**ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY SCHOOL OF GRADUATE STUDIES**

**FACULTY OF TECHNOLOGY**

**DEPARTMENT OF CIVIL ENGINEERING**

# Investigation on the water balance pattern of Lake Ziway

Thesis Submitted To School Of Graduate Studies in Partial Fulfillment

Of the Requirement for the Degree of

Master of Science

In

Civil Engineering

(Major in Hydraulic Engineering)

By

Yenenesh Alemayehu

Major Advisor: Habtamu Itefa (Dr.Ing)

May 17, 2017

Addis Ababa

## DECLARATION AND COPY RIGHT

Yenenesh Alemayehu Yoseph, declare that this thesis is my original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

______________________________

Signature

# APPROVAL PAGE

This thesis entitled with "**Investigation on the water balance pattern of Lake Ziway"** has been approved by the following examiners in the partial fulfillment of the requirement for the degree of Masters of Science in **Hydraulic Engineering.**

**Date of Defense: June 4, 2017**

Principal Advisor

1. Dr. Ing. Habitamu Itefa ______________ __________

Signature Date

**Members of the Examining board:**

1. Dr. Elias ____________ ___________

External Examiner Signature Date

2. Dr. Brook Abate ____________ ___________

Internal Examiner Signature Date

3. Mr. Addisu Bekele ____________ ___________

Head, Civil Eng'g Department Signature Date

3. Dr. Brook Abate ____________ ___________

Dean, College of Architecture and Civil Engineering Signature Date

# CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "**Investigation on the water balance pattern of Lake Ziway"** in partial fulfillment of the requirements of the degree of masters of Science in **Hydraulic Engineering**.

*Dr. Ing. Habitamu Itefa*

Principal Advisor

# ACKNOWLEDGMENT

Above all I thank the almighty of GOD for his mercy and grace upon me during all my works and in all my life.

I would like to express my deepest gratitude to my advisor Dr. Ing. Habitamu Itefa for his most Supports, constructive, professional advice and comments starting from title selection to accomplishment of this thesis.

Next I would like to thank Mr. Ashenafi Likassa , who has always been available to advise me and willing to bring in his research experience, and from whom I have learned so much , especially with regard to HBV model.

I am very grateful to Addis Ababa Science and Technology University, Department Of Civil Engineering for allowing me to take part in the Master program and for Ethiopia Road Authority (ERA) for financial support. My recognition also extend to staff of Ministry of Water, irrigation and energy (MoWIE) , especially in the Department of Hydrology GIS Library and irrigation, National Metrological Service Agency, Oromia Irrigation Development Authority(OID) and Agricultural and rural development (MoARD) offices for providing me with relevant data and materials.

My special thanks go to my friends Eng. Tesfay Gebresadkan for his support and comments, Eng. Tsega Weldselassie for giving me important suggestion on the HBV model and Eng. Tsegaye Weldu for helping me editing.

Finally I thank all who in one way or another contributed in the completion of this thesis. My class classmates are all acknowledged, especially Nugussie and Yodit deserves special thanks. Last but not least, I also thank my family who encouraged me and prayed for me throughout my life time.

## Table of content

## LIST OF FIGURE

# LIST OF TABLE

# LIST OF ACRONYMS

| | |
|---|---|
| Alfa | Parameter defining the non –linearity of the quick runoff reservoir in the HBV model |
| Beta | Parameter in soil moisture routine in the HBV model |
| DEM | Digital Elevation Model |
| FAO | Food and Agricultural Organization |
| FC | Parameter defining the maximum soil moisture storage in HBV model |
| HBV | Hydrologiska Byrans vattenbalansavdelning (hydrological burea water balance |
| Hq | Parameter representing the high flow rate in the HBV mode |
| GIS | Geographical Information System |
| KHQ | Parameter representing a recession coefficient at a corresponding reservoir volume in the HBV model |
| K4 | Recession Coefficient for Lower Response Box |
| Lp | Parameter defining a limit where above the actual evapotranspiration reaches the measured potential evapotranspiration in the HBV model |
| LULC | Land Use and Land Cover |
| Masl | Mean at sea level |
| MoWIE | Ministry of Water, Irigation and Energy |
| NSE | Nash-Sutcliffe Efficiency |
| NMA | National Metrological Agency |
| PERC | Percolation from upper to the lower response box (mm/day) |
| SHMI | Swedish Metrological and hydrologic Institute |

## Abstract

*Lake, with one of the largest freshwater lakes in the rift valley of Ethiopia is very essential for agricultural, industrial and domestic water supply as well as stabilizing of ecosystem in the region. However, the total amount of water available in the lake has been diminished which resulted from the rapid increasing of population and hence expansion of industrial activities and irrigated agricultural around the lake. The objective of this study was estimating the hydrological fluxes and amount of water flowing to and from the lake. The conceptual rainfall-runoff model, HBV was used to model the hydrological components and over all water balance of the lake. Runoff from both gauged and un-gauged sub-basins of the basins were estimated using this model. Flows from un-gauged sub-basins were estimated by using spatial proximity method. Runoff was simulated for the period of 1993-2012. The HBV model was calibrated with the datasets from 1993-2005 and validation using an independent data from 2006-2012. The performance of the model was evaluated by comparing observed and simulated runoff and found to be acceptable with NSE value of 0.81 and 0.80 during the calibration and 0.75 and 0.73 during validation period for Meki and Katarr sub-basins, respectively. Results indicate that total areas of 1212 km2 un-gauged sub-basins are estimated 8.3% the total inflow to the Lake. This study indicates that annual inflow components of lake water budget showed declined trend whereas outflow components (evaporation and abstraction) showed increasing trend. Water abstraction had a significant role in temporal variation on lake level during average to low rainfall years. The declining of outflow of Bulbula River from this lake and rising in annual evaporation rate from the lake water surface certainly will be responsible for changing of this Lake to Endorheic Lake in near future. Therefore, it is recommended to look a solution for minimization of outflow components by considering future sustainability of the lake.*

*Key words: HBV, Regionalization, Lake, Water Balance*

# CHAPTER ONE

## 1 Introduction

### 1.1 Background

Water is one of the most essential resources for life on Earth. An adequate and continues supply of water to meet agricultural, industrial and domestic is a basic need for all societies. However, the total amount of water available and its spatial and temporal variability has always been a problem for the accelerating demand of water increase rapidly with the growing of population, industrial activities expand and irrigated agriculture continuously to increase. According to figures from United States geological survey about 97% of all water is in the oceans which is saline and unusable directly, out of the remaining 3% water in rivers and lakes, where most of the water we use in our everyday life activity, accounts for only about 0.3 % (USUG, 2012) .

The competition water resources are pronounced and sometimes lead to conflict among different users. This has led to scientific approach to water resources planning, development and management. Among these approaches is the assessment of Lake Water balance is it reliefs to understand the behaviour of the watershed by understanding of surface, subsurface and interaction between water bodies. And Proper utilization of these resources necessitates assessment and management of the quantity and quality of the water resources both spatially and temporally (Amirew, 2006).

Shortages of water for different use at this time are a big problem in Ethiopia. The country is generally rich by nature in water resources it has nine major rivers and twelve big lakes (www.ethiovisit.com). However, an improper utilization of these resources leads to scarcity fresh water. Lake is one of the largest fresh water lakes in the rift valley in Ethiopia and it’s a used for drinking water, small scale commercial fishing and small-and large scale agricultural irrigation. Beside of this it has home of many bird populations, resident for hippopotamus and fish. The economy of the town depends on the lake, based on fishing and horticulture.

Lake Watershed requires proper planning and management of water resources. The watershed has two rivers inflow into Lake and one river outflow from the lake. Most of the inflow is coming from the two major rivers Meki and the Katarr Rivers and one outflow from the lakes by connecting to Bulbula River (Legesse, 2004). Global change of climate, uncontrolled abstraction of water and human interference of the watershed will surely change the hydrologic balance of the lake. Currently the lake is used for multi purposes like irrigation, water supply, fishing, transportation, recreation and feeding fresh water to Lake Abiyata through Bulbula River (Wondifraw, 2008). Since, the water resource potential in the watershed in general and the Lake water balance components in particular is poorly understood.

Thus, hydrological models are developed to guide the formulation of water resource management strategies by understanding spatial and temporal distribution of water resources (Dingman, 2002; Liden and Harlin, 2000). Hence, the same is will apply in Lake Watershed.

## 1.2 Statement of the Problem

The availability of water resource is quite essential for both the society and the ecosystem. However, the available water resource is utilized with equitable approach of the supply and demand and with a careful consideration of sustainability; to achieve the demands of the future generation will remain unanswered. Lake Watershed seems to face such a problem in the near future.

Lake is one of the largest fresh water lakes in the rift valley in Ethiopia. The incredible development in the past in agricultural, domestic water supply, urbanization, horticulture and floricultural enterprise and planned to be used in the future which has taken place in the watershed has increased the rates of water used from the lake significantly. Unplanned and unbalanced utilization of water are the most series problems for the lake Ziway. Among the major problems faced in the lake is uncontrolled water abstraction practice from the Lake Ziway and tributary rivers are common.

Assessment of the water availability in the watershed is essential which shall be addressed through water balance study.

## 1.3 Objective

### General objective

The main objective of this study is to establish investigating the hydrological dynamics and establishing monthly water balance of Lake

### Specific objective

- Calibration and validation of hydrological model for Lake
- Estimating of ungagged Sub basins stream flow using parameters transfer and their contribution to the Lake.
- Identifying the major hydrological components
- Estimating the water balance of the lake

## 1.4 Research Question

To address the above mentioned objective the research questions are:-

- What are the dominant components of the hydrological dynamics controlling hydrological behaviour of the Lake?
- How large are the inflow from un-gauged catchments to the lake?
- Does the Lake volume rise or diminish?

## 1.5 Scope of the study

This study focuses mainly for estimating the hydrological dynamics of the lake, establishing monthly water balance component, and lake volume by assessing the hydrological and meteorological data for past twenty years for specific watershed of Lake Ziway.

## 1.6 Significance of the study

This research has a profound a significant role to assessing the available water resources of the lake and the extent to which it is to be utilized, and for future sustainable utilization of water resources of the lake and has play its own parts to fill the gaps of other research works.

The research findings will be an input for water resource managers, policy makers and other concerned authority in planning and designing to threat Ziway Lake.

## 1.7 Thesis outline

This thesis is organized into five chapters:

Chapter one covers the general introduction to the study with emphasis on global water balance, statement of the problem, objective of the study, question and hypothesis. Chapter two deals with literature review on hydrological balance of the Lake. This involves the selection of the appropriate model to use, data required and how HBV can be used to obtain the required data. Chapter three gives the location and general watershed characteristics of the study area and it outlines the research methodology employed in this study. The approaches used for this study are included and discussed. Chapter four concentrates on HBV model simulation, model calibration and validation, estimation of runoff from un-gauged sub basins and spreadsheet water balance modeling of the Lake. Chapter five summarizes the entire study by outlining a brief conclusion, and forwarding some recommendation.

# CHAPTER TWO

## 2 Literature review

### 2.1 Hydrology and Hydrological cycle

Hydrology is defined as it is a science that deals with the occurrence, circulation and distribution of water on the earth and earth's atmosphere (subramanya, 2008), (Dingman, 2002). The physical process that controls the distribution and movement of water are best understood in terms of the hydrologic cycle. It is systematization that transfers water from the oceans to the surface and from the surface to the subsurface environment and from plants to the atmosphere that surrounds our planet.

The hydrological cycle is a very vast and complicated cycle in which there are a large number of paths of varying time scales. Further, it is a continuous recirculating in the sense that there is neither a beginning nor an end or a pause ( (subramanya, 2008; Ven Te Chaw, David R. Maidment, Larry W.Mays; Ven Te Chaw, David R. Maidment, Larry W.Mays).Figure 2.1 show as a diagrammatic representation of the hydrological cycle.

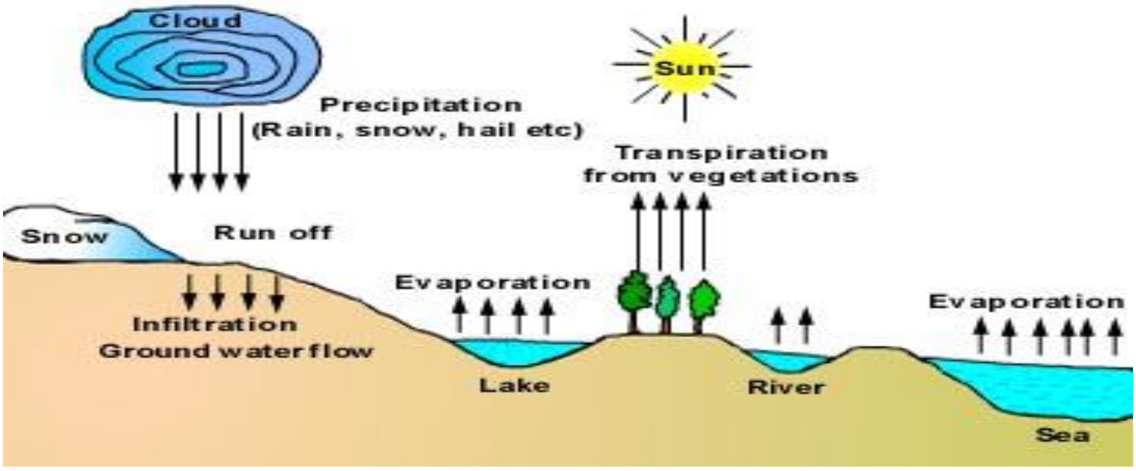



Figure 2-1 The hydrological cycle

Source: principal components of a hydrological cycle (adapted from illustration from trenberth et al.., 2007, estimates of global water budget and its annual cycle using observational model data, journal of hydro meteorology.)

In many hydrology books indicated that hydrologic cycle has generally four fundamental stages: temporary storage, evaporation, rainfall and runoff, Water may be stored temporarily in the ground, in oceans, lakes, and rivers, and in ice caps and glaciers. It evaporates from the earth's surface, condenses in clouds, falls back to the earth as rainfall (rain or snow), and eventually either runs into the seas or re-evaporates into the atmosphere. Almost all the water on the earth has passed through the water cycle countless times.

The fundamental components of the hydrologic process are rainfall; it plays a key role in repeating natural water resources. It occurs in three moderately vary climatic zones, movements of water in the atmosphere, in the surface and subsurface.

The ability to understand and model hydrologic processes is becoming increasingly important because the need to predict the effects of change in land use and climate to water resources. This is studied by the water balance techniques, one of the main subjects in hydrology are a means of solution of important theoretical and practical hydrological problems.

### 2.1.1 Water balance

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. Water balance is the ratio between water inflow and outflow estimated for different space and time scale, for any arbitrary volume and during any period of time, the difference between total input and output will balanced by the change of water storage with in the volume.

In general use of water balance technique implies measurements of both storages and fluxes (rates of flow) of water, though by appropriate selection of the volume and period time for which the balance will apply (Shiklomanov, 1974).

The study of the water balance structure of lakes, river basins, and groundwater forms a basis for the hydrological substantiation of projects for the rational use, control and re-distribution of water resources in time and space. Knowledge of the water balance assists the prediction of the consequences of artificial changes in any hydrologic regime such as streams, lakes, and groundwater. Information on the current water balance of river and lake watersheds for short time intervals (season, month and weekly) is used for operational management of reservoirs and for the compilation of hydrological forecasts for water management (Shiklomanov, 1974)Therefore, knowledge of water balance is very essential for studies of hydrological cycle. It is possible to compare individual sources of water in a system over different periods of time and established the degree of their effect on the variations in the water regime.

The water balance equation for any natural area such as a river basin or water body indicates the relative values of inflow, outflow and change in water storage for the area or body**.** Precipitation, evaporation, river runoff and ground water outflow not drained by river system are basic components determine water balance. Besides these, there are minor components, too, e.g. moisture due to atmospheric, water vapor, condensation, deep artesian water outflow or recharge of deep aquifers, water losses etc….according to investigations, however, these components are very small if related to large river basins, regions and globe so they are no importance for water balance computation, so they can be ignored ( (UNESCO, 2008), Dankers 2001).

The water balance of a watershed is affected by different natural and anthropogenic (manmade) effects. Several studies have shown that hydrological responses vary with changes in land use and land cover type. Change in climate, land use/land cover and anthropogenic effects have significant impacts to alter the hydrological cycle as well as the type and abundance of water resources, which may be changing the behavior of lakes and watercourses.

### 2.1.2 Water Balance Equation

A water balance is based on the principle that any mass is conserved within a Specified control of volume on specified time of period. Water balance as the amount of a conservative quantity entering a control volume during a defined period minus the amount of quantity leaving the control volume during the same time period equals the change in the amount of the quantity stored in the control volume during the same period (Dingman, 2002)

$$\frac{\Delta s}{\Delta T} = inflow - outflow \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2-1}$$

Where: -

$\frac{\Delta s}{\Delta T}$ is the change in storage for a selected period of time ($L^3T^{-1}$)

The genera water balance equation of a Lake can be written as:-

$$\frac{\Delta s}{\Delta T} = (\boldsymbol{p} + \boldsymbol{SI_{gauged}} + \boldsymbol{SI_{un-gauged}} + \boldsymbol{GW_I}) - (\boldsymbol{E_o} + \boldsymbol{S_o} + \boldsymbol{GW_o}) + \boldsymbol{SS} \text{...Equation 2-2}$$

Where:-

P _ Lake area rainfall ($L^3T^{-1}$)

$SI_{gauged}$ _ Surface water inflow from gauged sub-basins ($L^3T^{-1}$)

$SI_{un-gauged}$_ Surface water inflow from ungauged sub-basins ($L^3T^{-1}$)

$GW_I$_ Sub surface water inflow into the Lake ($L^3T^{-1}$)

$E_o$ _ Open water evaporation from the Lake Surface ($L^3T^{-1}$)

$S_o$ _ Surface water outflow from the Lake

$GW_o$ _ Subsurface water outflow from the Lake and

$SS$ _ sink source term ($L^3T^{-1}$)

## 2.2 The lake

Lake is a natural large sized depression formed within the surface of the earth filled up with fresh or salty standing water or a lake is a body of water is surrounded by land. A lake is another component of Earth's surface water. A lake is where surface-water runoff (and maybe some groundwater seepage) has accumulated in a low spot, relative to the surrounding countryside.

The sources of lake water is atmospheric rainfall that reaches the lakes directly or by means of springs, brooks and surface runoff from the watershed area, contributing to a particular lake. Sometimes, underground water through some spring also enters the natural depression and gets collected there, forming a lake. Lakes form and disappear over the course of varying lengths of geologic time. They may evaporate, as the climate becomes more arid, or they may fill up with sediment, leaving a bog or swamp in their place. In arid regions where rainfall is insignificant and evaporation excess, lake levels rise and fall with the seasons and sometimes dry up for long periods. The dissolved matter, brought by tributary streams, varies in composition with the nature of the rocks in the local drainage system (Garg, 2005; IAEA et al., 2005).

The quality of water in a lake is generally good and does not need much purification. Larger and older lakes, however, provides comparatively purer water than the smaller and newer lakes (IAEA et al., 2005).

Lakes are highly valued for their recreational, water supply qualities, and the water they contain is one of the most treasured of our natural resources. Lakes constitute important habitats and food resources for a various collection of fish, aquatic life, and wildlife. But lake is vulnerable to environmental changes or climatic parameters. Exposed to external effects from the atmosphere, their watersheds, and groundwater, lakes are subject to change through time or Lakes are particularly vulnerable to change in climate parameters. Variation in air temperature, rainfall, and other meteorological components directly cause change in evaporation, water balance, lake level, ice events, hydro -chemical and hydro-biological regimes, and the entire lake ecosystems. Under some climatic conditions, lakes may disappear entirely. An important distinction is made between closed (endorheic), lakes with no outflow and open (exorheic) lakes which are drained by out-flowing rivers. Small endoreic lakes are most vulnerable to a change in climate; there are indicators even relatively small changes in inputs can produce large flucations in water level and salinity and in exorheric lakes also may be sensitive to changes in the amount of inflow and the volume of evaporation (UNESCO, 1974).

Human activities can further accelerate the rates of change. If the causes of the changes are known, however, human intervention (lake-management practices) sometimes can control, or even reverse, detrimental changes.

Globally, lakes store the largest volume of fresh water about 23,000 $km^3$ ( (UNESCO, 1974)The Ethiopia lakes occupy a total area 7500$km^2$ ( (Selshi Bekele Awulachew, Aster Denekew Yilma, Makonnen Lousged W.Loiskandl Tena alamarew and Mekonnen ayana, 2007). Lake Ziway can store about 1466 $Mm^3$ fresh water at average of 440$km^2$ with in average depth of 2.5m (Ayenew, 2007).

## 2.3 Hydrological model

### 2.3.1 Definition of modeling

Most hydrological systems are extremely complex, and we cannot hope to understand them in all detail. A quantitative model can be used to explore cause-and effect relations and to determine values of physical variables that are too costly or difficult to measure directly (Chong-yu Xu, 2002). Hydrological Models have long been used in water resources is to gain better understanding of the hydrological phenomena operating the catchment,  how changes in the catchment may affect these phenomena or objective of modeling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting. Hydrological model is the mathematical representation of the flow of water and its constituents on the land surface or subsurface environment.

Hydrological models are classified based on different criteria however the most convenient classification based on physical process are empirical (black box model), conceptual and physically-based models. Empirical models use statistical relationship to relate climate inputs to hydrological properties such as regression analysis. The conceptual model attempts to give an idealistic representation of the catchment determining the water balance at different time scale through the use of parameters. On the other hand, the physical-based or water balance models uses equations to simulate the movement of water throughout the system unite it leaves. They are further classified as either lumped or distributed based on the spatial scale. In lumped models, the spatial variability in hydrologic parameters is not accounted, meaning is averaged or assumed uniform over the system, catchment response is evaluated only at the outlet. Lumped models do not take into account spatial heterogeneity across the modeling domain. Rather, they simulate a spatially averaged hydrologic system. Whereas in Distributed model spatial variability is explicitly accounted by assuming uniformity over smaller modeling units by subdividing the bigger system based on physical properties. (Spatially distributed models, however allow for spatially varying precipitation, temperature, and other climatic variables, and the spatial occurrence of watershed characteristics such as soils, slope, and land cover types (Chow, Maidment, & Mays, 1988)

### 2.3.2 Why modeling

Hydrological process and water resource issues are commonly examined by use of distributed watershed models (Garbrecht,J and L.W.Martz , 2000). A water balance models forms an important tool for the analysis of the hydrological behavior of the catchment. They are applied for simulation and forecasting purposes. They are also used to assess the system sensitivity to certain natural or imposed impacts such as caused by climate and land use change (Rientjes, 2007).

### 2.3.3 Selection of models

Comprehensive and physically based watershed models have the capability of simulating hydrologic, sediment, and water quality processes at a watershed scale. There are many hydrological models available for hydrology simulation and analysis. Some of them are WATBAL, WEAP, HEC HMS, HBV, SWAT, TOPMODELS, and HFAM. These differ significantly on their way of process. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. (Beven, 2001) Suggested to select a model for a specific application, often four major issues are involved. Firstly the conceptual base of the model should capture the outputs needed to meet the aims of a particular project (model output). Secondly consider models which are readily available and whose investment of time and money appeared worthwhile (price of software technical support and data) and thirdly make a list of the inputs required by the model can be provided within the time and cost constraints of the project (availability input data), finally Prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes (hydrological process of the model)

According to (Bergstrom, 1991), the model must be on sound of scientific foundation, it must be possible to meet its demands in most areas, its complexity must be justified by its performance, it must be properly validated and the user must be able to understand the model.

Therefore, a semi distributed physically based model HBV is selected for this particular study by considering the factors stated above and it's a basin scale model used to simulate rainfall-runoff to forecast most likely water balance of Lake .

There are water abstractions points along the rivers that affect the runoff measured at the gauging stations. These abstraction need to be taken into account during the modelling process. According to the (SMHI, 2006) HBV manual, the model can be model abstractions from rivers as well as from lakes. The model has a daily time step and three climate variables are required as input. The detail of the model structure and input data are explained in the section 2.4

## 2.4 HBV

The HBV model can best be described as a semi-distributed conceptual model for continuous calculation runoff, which includes conceptual numerical descriptions of hydrological process. The HBV was originally developed by SMHI in the early 70's to assist hydropower operations and it was named after the abbreviation of Hydrologiska Byrains Vattenbalans-avdelning (hydrological bureau water balance section).HBV model simulates daily discharge using rainfall, air temperature, potential evapotranspiration and daily runoff data for calibration. The model consists of subroutines for precipitation and snow accumulation, for soil moisture accounting where ground water recharge and actual evaporation are coupled and it consists of a response routine, transformation function and simple routing procedure.it has applied to different climatic condition in more than 40 countries.

### 2.4.1 Model structure

The model simulates daily discharge using daily precipitation, air temperature, and potential evaporation as input. Precipitation is simulated to be either snow or rain depending on whether the temperature is above or below a threshold temperature. And stream flow data is required for calibration. The model uses sub basins as primary hydrological units. For basins of considerable elevation range a subdivision into elevation zones can be made and simple classification of land use is made (Rientjes, 2007).

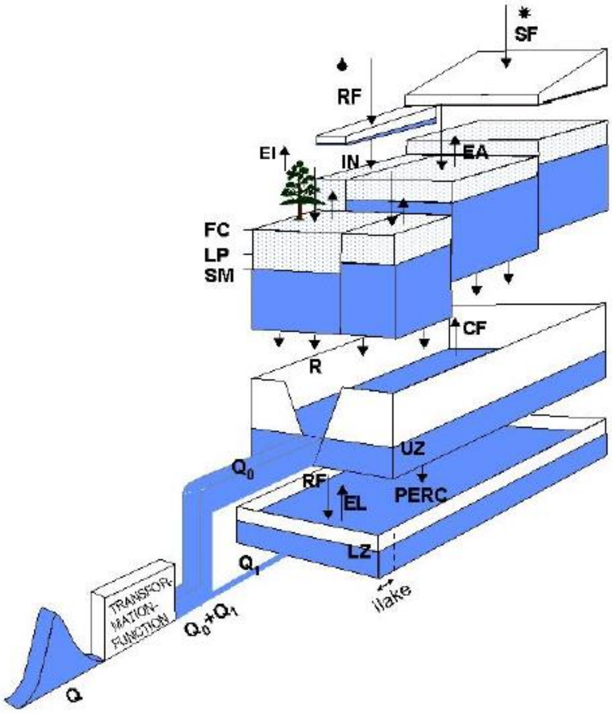



Figure 2-2 schematic presentation of the HBV model **(IHMS, 2012)**

Where: SF: snow fall, RF: rainfall, EI: Evapotranspiration, IN: Infiltration, EA: Actual evaporation, Fc: maximum soil moisture storage, SM: compound soil moisture routline, CF: capillary rise, R: Seepage, UZ: Upper zone reservoir, $Q_o$: direct runoff from upper reservoir, EL: Lake Evaporation, PERC: percolation capacity, LZ: lower zone reservoir, $Q_1$: base flow lower reservoir

- It is noted that all units are in mm

## 2.5 HBV model components

### 2.5.1 Precipitation and snow accumulation routine

HBV model requires daily precipitation, daily air temperature and long month potential evaporation. Precipitation calculations are made separately for each elevation /vegetation zone within a sub basin. To separate between snow and rainfall a threshold temperature is used:-

RF: *pcorr.rfcf. P* if T > *tt*

SF: *pcorr.sfcf.* P if T< *tt*

Where:-RF: rainfall, SF: snowfall, P: observed precipitation (mm) and T: observed temperature ($^{o}$C), *rcfc*: rainfall correction factor, *scfc:* snowfall correction factor and *pcorr:* general precipitation correction factor

### 2.5.2 Soil routine

The soil moisture accounting in HBV model is based on a modification of the bucket theory in that it assume a statistical distribution of storage capacity in the basin. This routine is the main part controlling runoff formation. This routine is based on the three parameters, β, lp and fc, as shown in the figure 2.3. Beta (β) controls the contribution to the response function (ΔQ/ΔP) or the increase in soil moisture storage (1- ΔQ/ΔP) from each mm of rainfall or snow melt. Limit for potential evaporation (Lp) is soil moisture value above which evapotranspiration reaches its potential value, and Field capacity (Fc) is the maximum soil moisture storage in the model (IHMS 2012).

Actual evapotranspiration from the soil equals the potential evaporation if SM/FC is above Lp while the linear reduction is used when SM/FC is below LP.

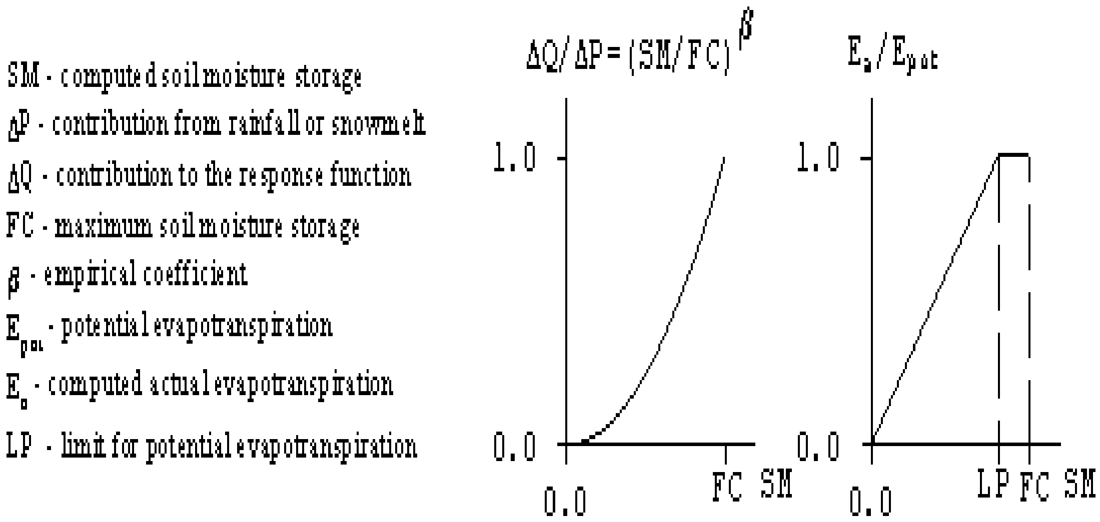



Figure 2-3 the soil moisture routine of the model **(IHMS, 2012)**

### 2.5.3 Response Function and Routing

The runoff generation routine is the response function which transforms excess water from the soil moisture zone to runoff. It also includes the effect of direct precipitation and evapotranspiration on a part which represents lakes, rivers and other wet areas. This routine contains two reservoirs that distribute the generated runoff in time to obtain the quick and slow runoff components of the hydrograph. The function consists of one upper, non-linear, and one lower, linear, reservoir. The lower reservoir is simple linear reservoir representing the contribution to base flow filled by percolation (*perc)* from upper reservoir. The outflow from the upper reservoir and the outflow from the lower linear reservoir are described by a function corresponding to a continuously increasing recession coefficient.

$$Q_o = K.UZ^{(1+alfa)} \text{......................} \quad \textbf{Equation 2-3}$$

$$Q_1 = K4 * LZ \ldots\ldots\ldots\ldots\ldots\ldots..\ldots.. \quad \textbf{Equation 2-4}$$

Where:

- K and k4 represents the recession coefficients from the upper and lower reservoir respectively
- Qo and Q1 represents reservoir outflow from upper and lower reservoir respectively in mm
- UZ and LZ represents upper and lower reservoir storage in mm

### 2.5.4 Transformation function

The runoff generated from the response routine ($Q=Q_1+Q_O$) will routed separately each one of the sub-basins through a transfer function in order to get proper shape of the hydrograph at the outlet of the sub-basin. This transformation function is a simple filter technique with a triangular distribution of the weight in the figure below. The time base of the triangular distribution is given by the parameter *maxbaz.*

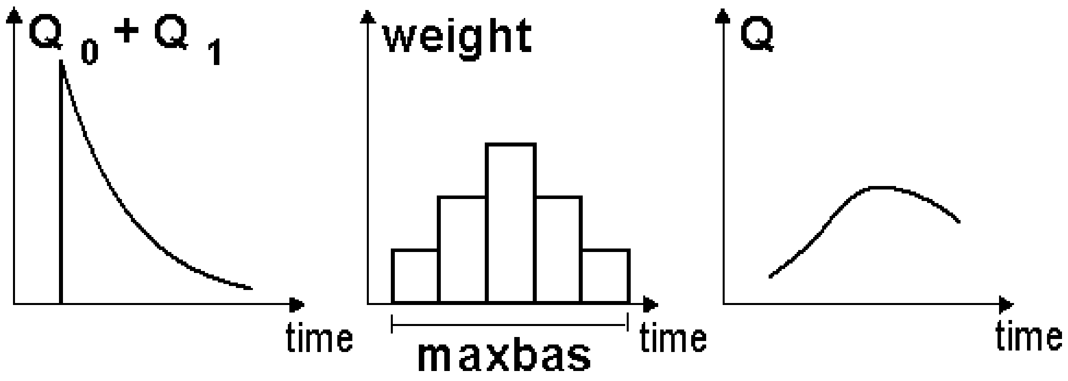



Figure 2-4 the transformation function **(IHMS, 2012)**

### 2.5.5 Objective function

To define the parameter value for all gauged sub basins and to establish the regional model, the initial values of the parameters will be calibrated against observed discharge where by the model parameters adjusted until the observed system output and the model outputs shows acceptable level of agreement between the observed system output and the model output, i.e the observed and modeled discharge ( (Booij, 2007)). Usually two different objective functions are considered these are goodness of water balance and overall goodness agreement of shape of the hydrograph measured by relative volume error and Nash-Sutcliffe coefficient respectively.

- **The relative volume error**

The relative volume error can vary between ∞ and -∞. The model achieves best when the value is become zero. In general the relative volume error ($RV_E$) less -5% to +5% shows that model performs well and -10% to +10% indicate a mode performer with reasonable performance (IHMS, 2012).

$$RVE = \frac{(\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i}))}{(\sum_{i=1}^{n} Q_{obs,i})}$$ **................Equation 2-5**

Where:-

- $Q_{obs,I}$ is observed discharge and $Q_{sim.i}$ is modeled simulated at time i

- **The Nash-Sutcliffe Coefficient**

The Nash-sutcliffel efficiency (Ns) coefficient is used to evaluate agreement between observed and simulated hydrological flows and is given as;

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - \overline{Q_{obs}})^2} \quad \text{...................Equation 2-6}$$

Where:-

- NS is Nash-Sutcliffe Coefficient
- $Q_{obs,I}$ is observed discharge
- $Q_{sim.i}$ is modeled simulated at time i
- $\overline{Q_{obs}}$ is average of the observed flow

Nash-sutcliffe model efficiency is range -∞ to 1 and Ns=1 indicates the simulated discharge is perfect match of the observed data. An efficiency of NS = 0 shows that the simulated discharge are different from the observed however an efficiency less than zero --∞<NS <0 happens when the observed data is better forecaster than the model and NS close to 1 is the more accurate the model is. In HBV, the NS ranges 0.8-0.95.

- **The mean error**

The mean error is the difference between the mean the observed and simulated discharge. The small error may not be indicating a good calibration and therefore it should be used with care (Rientjes, T.H., 2007).

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right) \quad \text{... ... ... .Equation 2-7}$$

Where:-

- $Q_{obs,I}$ is observed discharge and $Q_{sim.i}$ is modeled simulated at time i

# CHAPTER THREE

# 3 Materials and Methods

## 3.1 Description of the Study Area

### 3.1.1 Location and accessibility

The study area, Lake and its watershed is found in east- central Ethiopia. Located in the Misraq Shewa zone of the Oromia region, it is about 160 kms south of the capital city of Addis Ababa, It has an open water area of 435 km2. Lake Ziway is the shallowest lake in the country; the maximum depth of the lake is 9m, while the average depth is only 2.5m and an elevation of 1636 m.a.s.l. (Dagnachew Legesse, 2005).Lake Ziway Watershed lies between 7°12’N to 8°28’N latitude and 38° 15’E to 39°17’E longitude. It covers a total area of about 7444 km$^2$.

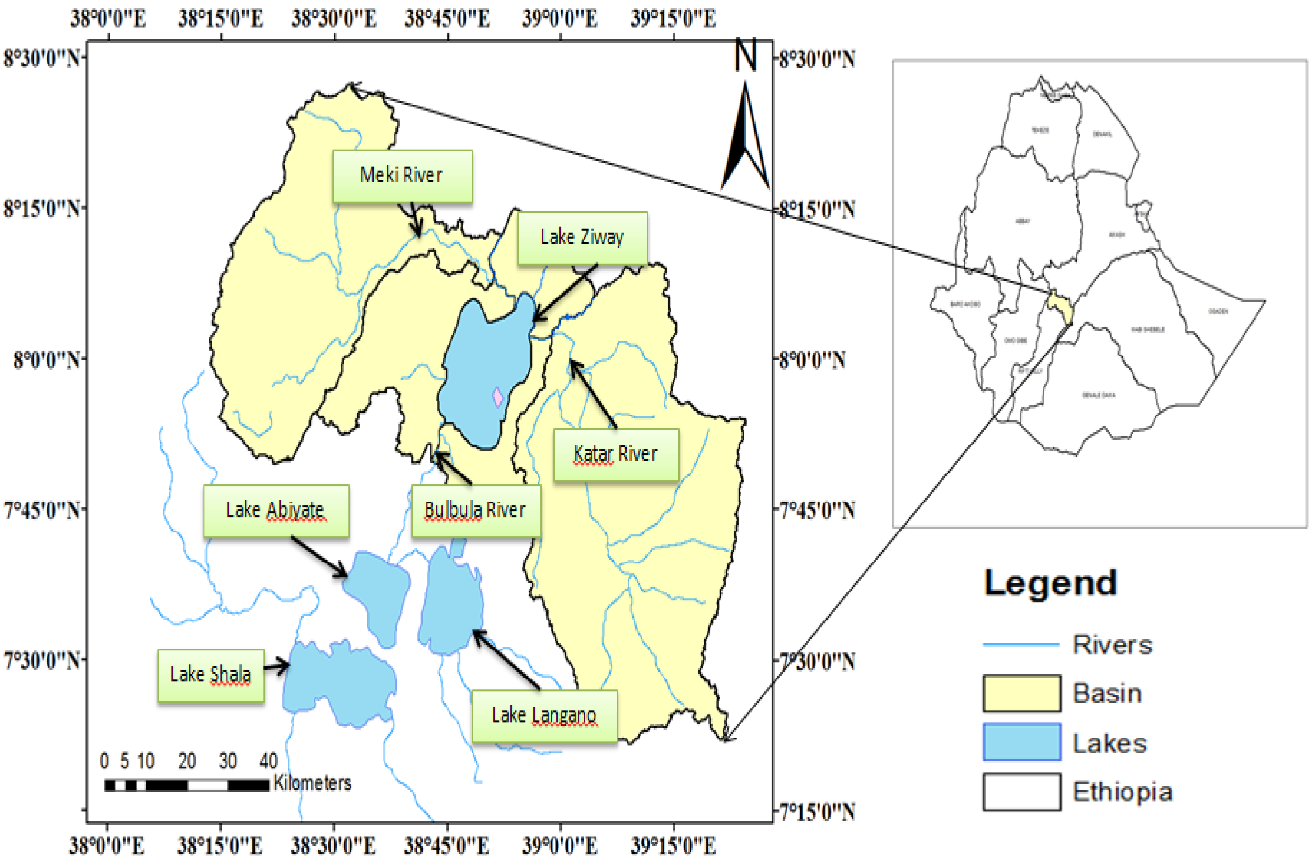



Figure 3-1 Location of map of the study area

The lake contains fresh water, which principally originates from the two incoming rivers, the Katarr River and Meki River and the rainfall. Both rivers are perennial rivers and one river, Bulbula, flowing out of the lake towards Lake Abyata. Mean annual precipitation and temperature of the watershed is 850 mm and 30°C, respectively.

The watershed is accessed by Addis Ababa-Mojo –Addis Ababa-Alem Gena-Butajira or Addis Ababa- Assela asphalt roads. The Intra watershed areas are accessed by numerous gravel and dry weather roads.

## 3.2 Data Collection and Analysis

For proper implementation of this study Arc Gis 10.3.1, HBV model and excel spread sheet were used for input data preparation, analysis and modeling purpose of the research. In general two types of data (spatial and time series data) were collected and used for this study. Spatial data and hydrological data were collected from Ministry of Water, Irrigation and Energy (MoWIE). The Meteorological data were gathered from National Meteorological Agency of Ethiopia (NMAE). The data collected were processed until they become an input to the model used. First spatial data (DEM, soil map and land use map) were defined using Arc-GIS with the same projection. At this step Watershed delineation were done for spatial input data. Secondly estimation of gauged and un-gauged stream flow was done by using HBV model. In the third and final stage this thesis work was of modelling of hydrological flux of the Lake Ziway were estimated and at the end some conclusion and recommendation are made. The schematic representation of the study methodology is shown in figure 1.

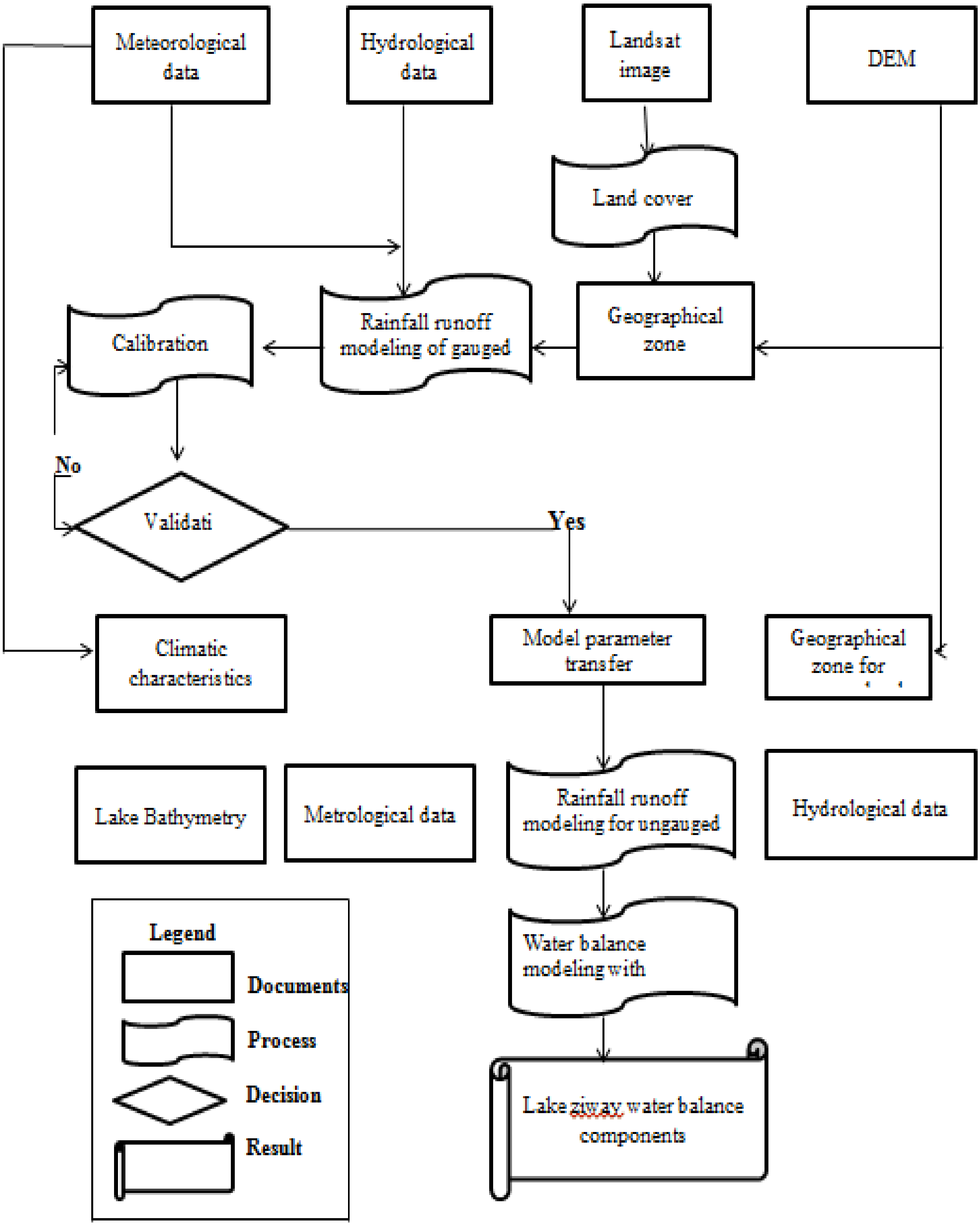



**Figure 3-2 Conceptual Framework of the research**

## 3.3 Spatial data collection and analysis

The Digital Elevation Map, Land use/Land cover map and soil map were collected from Ministry of Water Irrigation & Energy.

### 3.3.1 Topography

Topography is generally uniform and quite well adapted to irrigation development surrounding Lake. The elevation ranges between 1595m to 4200 m. a.s.l. which is extracted from DEM has resolution 30mX30m. The mean elevation of the basin is found to be 2700 m.a.s.l. only a third of the whole watershed area has an elevation below 1867 m.a.s.l and more than 56% of the whole watershed has an elevation more than 2000 m.a.s.l, which magnifies the upland terrain of most parts of the area. The original landscape of the watershed by far has been replaced by residential, commercial or agricultural development activities (OEPO, 2005).

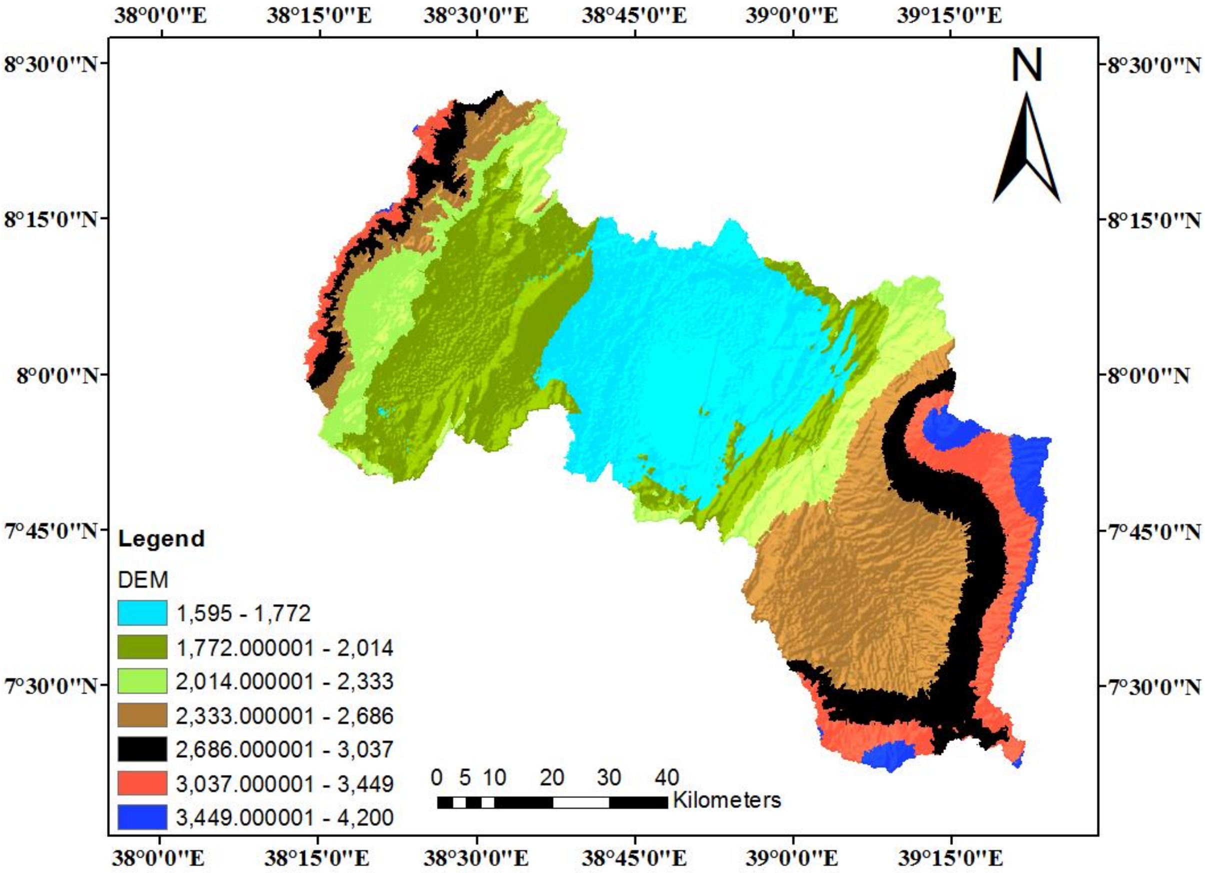



Figure 3-3 Topography of Lake Ziway watershed

### 3.3.2 Soils

Most of the rift valley like Lake Watershed is covered by volcanic rocks that mainly consist of ignimbrites, basalts, acidic lava, volcanic ash and pumice (Tesfaye Chernet, 1982). The soils in the Meki sub watershed of the study area are majorly covered with Cambisols which is dark brown or black clay loam underlain by greyish and yellowish brown soil which is a wide variety of agricultural uses. Around the lake, the soils are covered with Andosols and small amount of Fluvisols and other soil groups, which are rapid weathering of porous volcanic material, resulted in accumulation of stable Organo mineral complexes and short-range minerals such as Allophane, Imogolite and Ferrihydrite which is used intensively cultivated with a variety of crop. The north-eastern and north-western shores of Lake have both saline and alkaline soil types along the profile (OEPO, A Review of the Current Status and an Outline of a Future Management Plan for Lakes Abiyata and Ziway, 2005). Katarr sub watershed covered by vertisols which is Mineral soils whose formation is conditioned by their parent material in which Soils developed in volcanic material, in residual and shifting sands.

Ten major soil groups in the study area are Vertisols 9.8%, Luvisols 22.4%, Cambisols 18%, Andosols 14.6%, Phaeozems 11.1%, and water body 15.2%, Nitosols 3.9%, Fluvisols 4.3%, and Xerosols 0.6% in combination with three horizon modifiers: Leptosols, Haplic Cambisols, and Drystric Nitisols collected from Ministry of Water, Irigation and Energy.

**Table 3-1 Soil properties of major soil tyupe in the study area**

| Major soil type | soil texture | Drainage condition |
|---|---|---|
| Andosols | sandy clay loam | well drained |
| Cambisols | clay to silty clay | moderately well drained |
| Fluvisols | silty clay | moderately well drained |
| Luvisols | clay to silty clay | moderately well drained |
| enitosols | sandy clay | well drained |
| phaeozems | sandy loam | well drained |
| vertisols | clay | poorly drained |

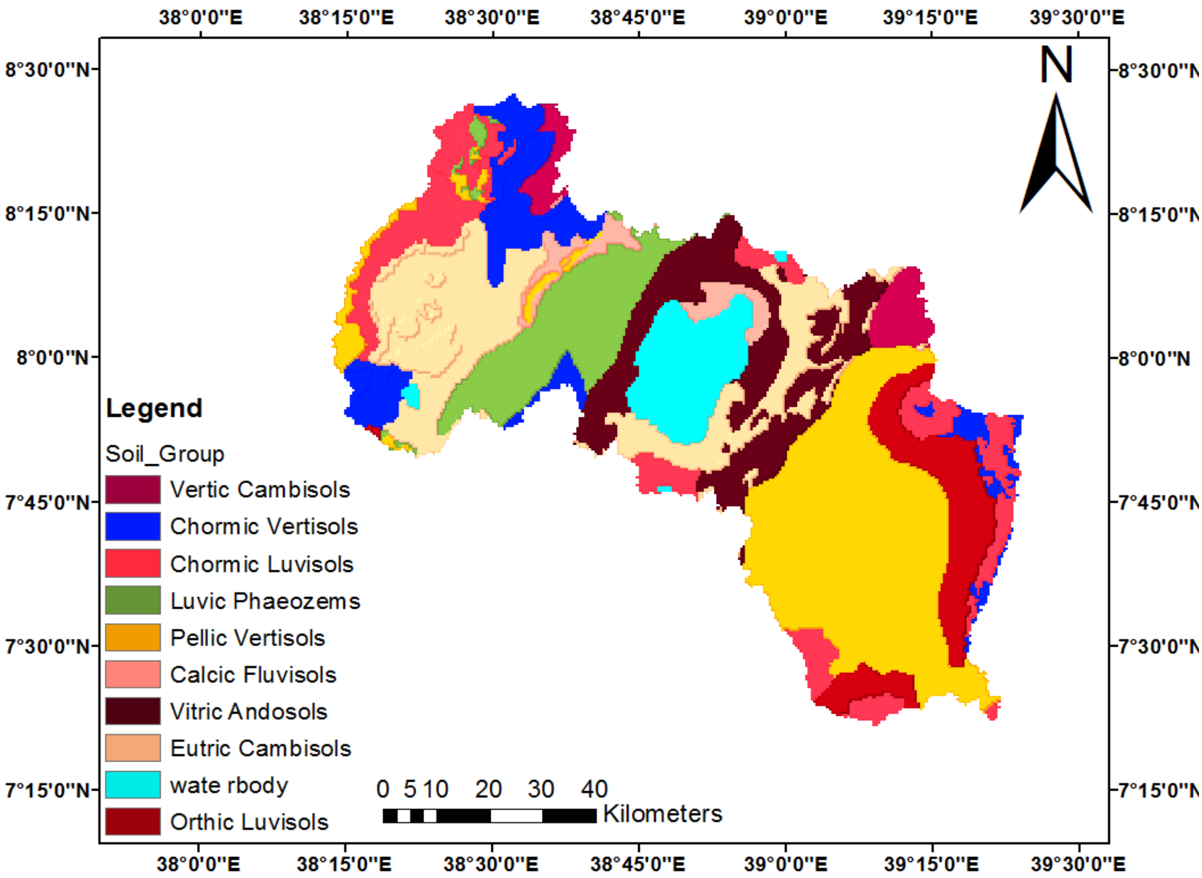



Figure 3-4 major soil groups of the study area as per FAO classification

### 3.3.3 Land cover

Agriculture has long history in the watershed. The land use of the study area can be categorized mainly cropland, grassland, forestland, settlements and wetland. During field visit in the study area some information gathered, irrigated agriculture is common mainly along the Meki, Katarr and Bulbula Rivers, and also around Lake.The major field Crops grown are teff, barley, maize, lentils, horse beans, chickpeas and field peas. Most important vegetables are grown under irrigation in many private and state farms. It includes beans (Fosolia) tomato, onion, cabbage and broccoli (Moti, 2002). Besides, floriculture is the newly growing agricultural activity. However, the dominant agricultural crops in the watershed are onion and tomato, which are cultivated by rotation.

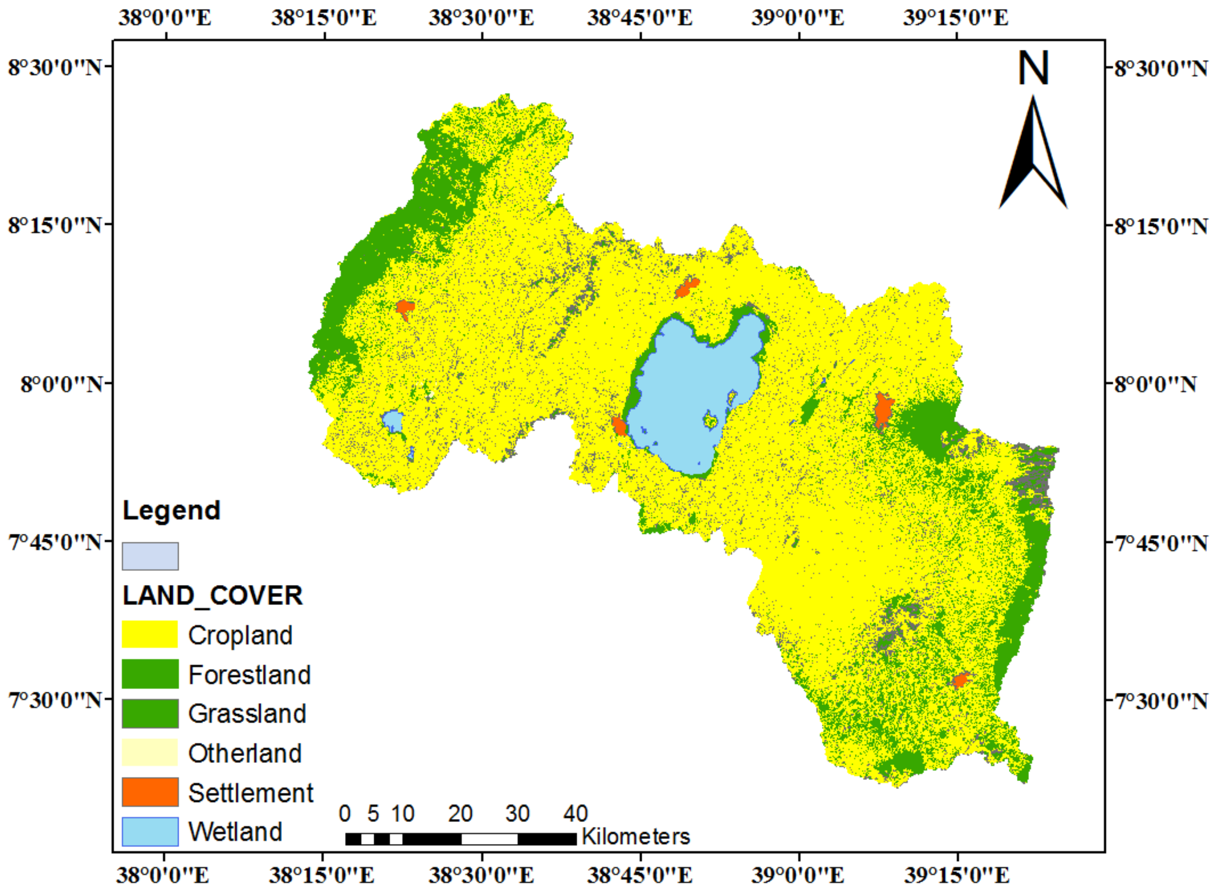



Figure 3-5 land covers of study area

### Table 3-2 Land use Land cover of the study area

| Major Land cover | description | % area coverage |
|---|---|---|
| Forestland | trees and other plants in a large densely wooded area | **16.4** |
| Cropland | Areas used for the production of crops | **52.46** |
| Grassland | Area that covered with grass | **18.9** |
| Wetland | lake and rivers | **1.08** |
| Other land | area used for the people settlement | **0.15** |
| Settlement | other areas | **11.01** |

## 3.4 Hydro meteorological data collection and analysis

### 3.4.1 Meteorological data collection

For this specific study, the necessary climate data were collected from the National Meteorological Services Agency (NMSA). The types of meteorological variables have been collected are like humidity, sunshine hours, and wind speed in addition to rainfall, maximum and minimum temperatures. The number of meteorological variables collected varies from station to station depending on the class of the stations. Some stations contain only rainfall data. The other group includes maximum and minimum temperature in addition to rainfall data. There are also stations which contain variables like humidity, sunshine hours, and wind speed in addition to rainfall, maximum temperature and minimum temperature. According to NMSA stations have been classified as station code.

***Code one (principal station)***:- are stations measuring rainfall, relative humidity, max and min temperature, wind speed and sunshine hours at which surveillance are taken every three hours.

***Code two (synoptic station):-*** measuring rainfall, relative humidity, max and min temperature, wind speed and shine hours surveillance are taken every 24 hours.

***Code three (ordinary stations):-*** only daily observe rainfall, daily max and min temperature.

***Code four (rainfall recording stations):-*** only observe daily rainfall amount.

Data of precipitation, max and min temperature, sunshine hours, relative humidity and wind speed were collected for 10 meteorological stations around the watershed and data used is from 1993to 2012. The locations of the station are described in figures 3-6.

#### 3.4.1.1 *Rainfall*

Precipitation is the major source of inflow into the watershed. Three main seasons characterize in the study area. The first one is the long rainy season in summer, which is from June to September and locally known as “kiremt” according to (Degafu, 1987) kiremt season accounts about 60-70% of the total annual rainfall. The second is dry period which covers from October to February and locally known as “bega”. Degefu indicated that occasional rains during this period bring 10-20% of the yearly average. The ‘bega’ season is known as the main harvest season in the area. The third season, which is locally known as 'belg' is of a 'small rain' season accounting for 20-30% of the annual amount, and stays from March to May. This rainfall is agriculturally very important in the south-eastern part of the country (OEPO, 2005).

In relation to statistical investigation of climate data, Ethiopia rainfall is erratic and subject to large special variability, which is largely determined by altitude. Area above 2500m may receive 1400-1800mm/year, mid altitude regions (600-2500m) may receive 1000-1400mm/year, and costal lowlands generally receive less than 200mm/year. (Halcrow, 1989).

Lake  watershed is located in the mid altitude regions; mean annual rainfall ranging from 1118 mm at Butajira  to 705 mm at Bulbula . At station near to the lake the mean annual rainfall is 742 mm. Figure 13 shows below the detail distribution rain fall in the station in Figure 3-12.

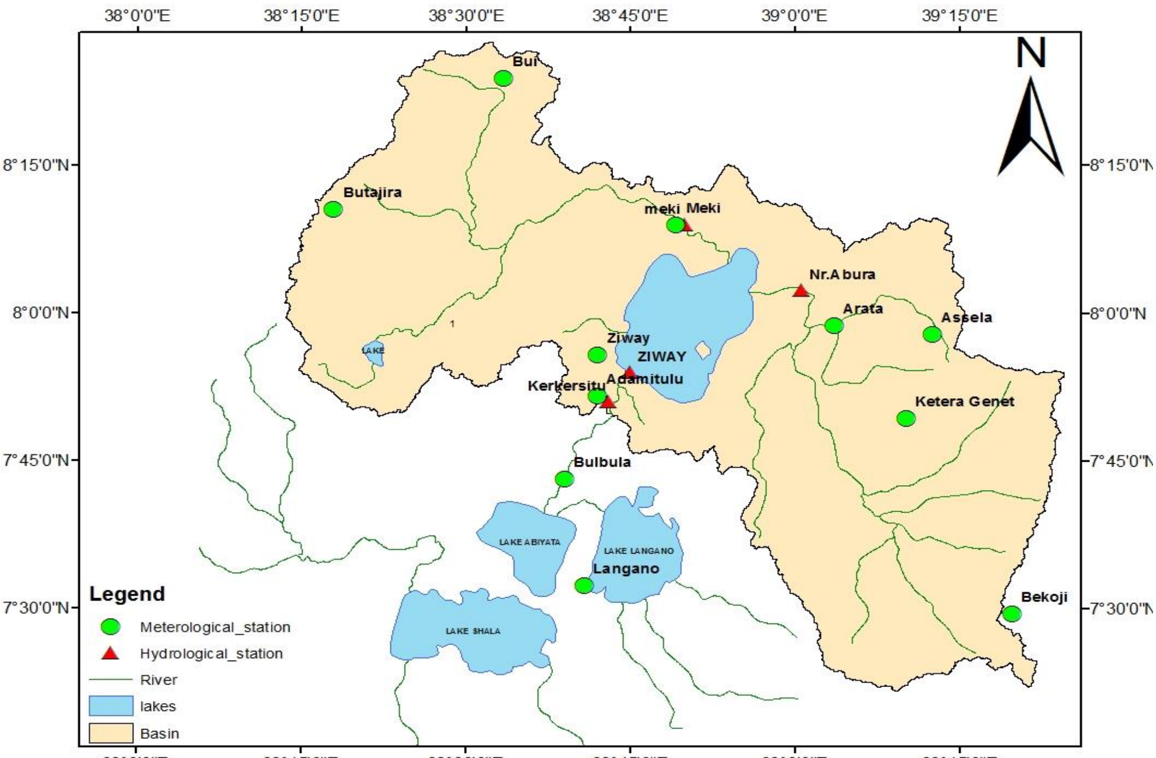



**Figure 3-6 Meteorological and hydrological gauging stations in the study area**

#### 3.4.1.1.1 Rainfall data analysis

**Filling in missing data**

While working with hydrological models, it is common to encounter missing weather data values from observed records for so many reasons. HBV model needs daily a continuous precipitation, max and min temperature and evapotranspiration data.

There are a number deterministic and stochastic weighting methods used for infilling missing rainfall data values, some of them are: inverse distance, Simple arithmetic averaging and normal ratio methods. In this study the missing data of rainfall data was filled by inverse distance weight method applied.

**Homogeneity test for selected Rainfall stations**

One of the methods to check homogeneity of the selected stations in the Watershed is the non- dimensional rainfall records and plotted to compare the stations with each other. This Non-dimensional value of the monthly precipitation was calculated by taking 20 years average value for each station. All stations non-dimensional values of the monthly precipitation were plotted together to compare the stations homogeneity with each other. Non dimensional values of the monthly precipitation of each station were computed by using the following formula.

$$P_i = \frac{P_{i,av}}{P_{av}} * 100 \text{ ………………… …Equation 3-1}$$

Where: - Pi is non - dimensional value of precipitation for the month in station i,

Pi,av over years (20 years) averaged monthly precipitation for the station i

Pav is over year's averaged yearly precipitation of the station i.

Figure…. shows the homogeneity test plot of selected stations within and around the Megech Watershed

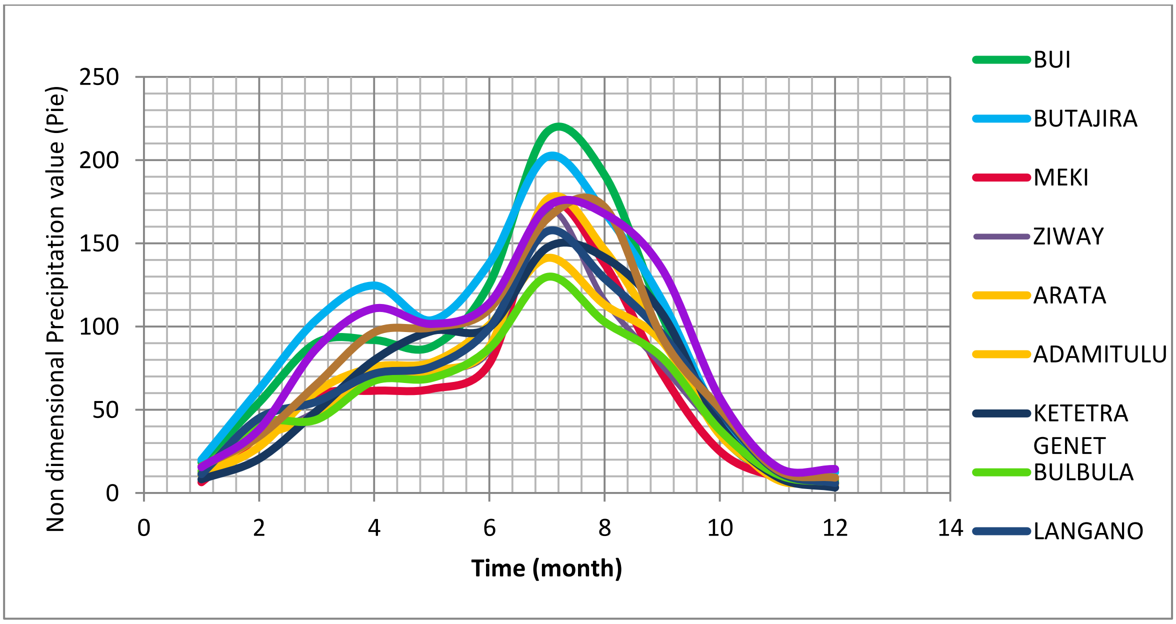



Figure 3-7 Homogeneity test plot of selected stations

The above homogeneity test plot shows that all of the rainfall stations used for this particular study was homogeneous and their rainfall pattern was found to be bi-modal with high rainfall season from July to September and min peak March to April rainfall.

**Double mass curve Analysis**

In this study consistency of rainfall data was checked by using double mass curve analysis method for the research period (1993-2012 G.C) The double mass curve is used to check the consistency of many kinds of hydrological data by comparing data for a single station with that of a pattern composed of the data from several other stations in the area. The double mass curve can be used to adjust inconsistent rainfall data, the graph of cumulative data of one variable versus the cumulative data of related variables is a straight line as long as the relation between the variables is fixed ration. Breaks in the double mass curve of such variables are caused by changes in the relation between the variables. The change may be due to changes in the method of data collection or to physical changes that affect the relation poor correlation between the variables. From Figure 3-8 the double mass curve the stations used in this study have not undergone a significant change during the base line period of the study

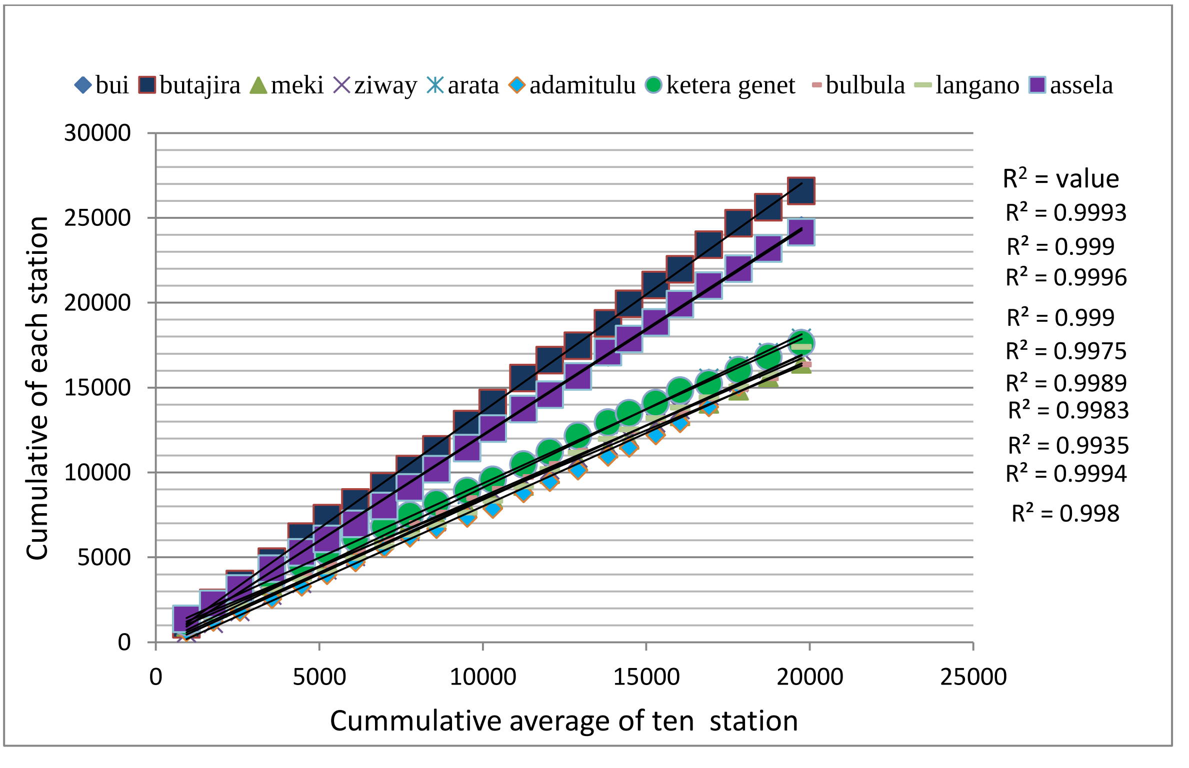



**Figure 3-8 Double Mass Curve Consistency test plot for all stations**

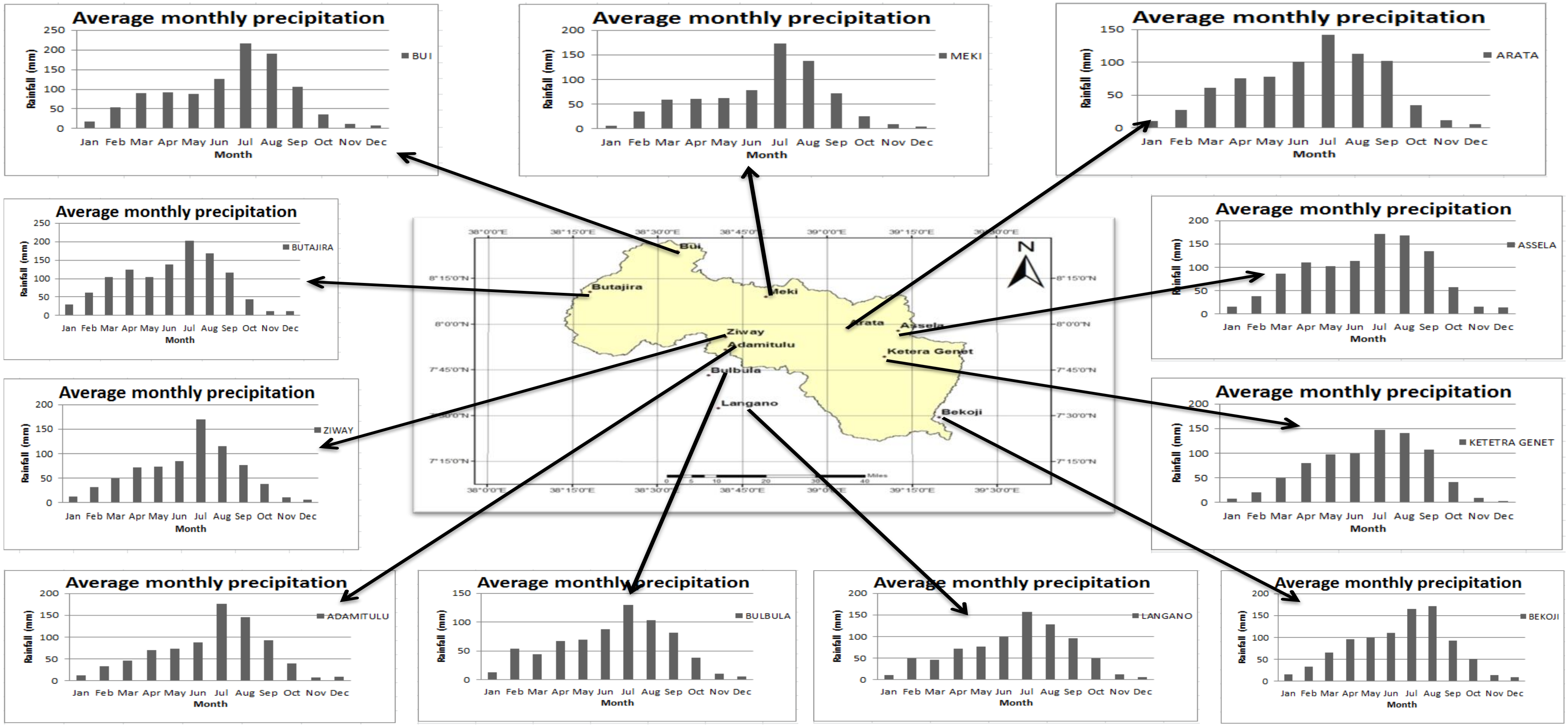



Figure 3-9 Mean Monthly rainfall distribution of different station in study area (1993-2012)

### 3.4.1.1.2 Temperature

Temperature varies considerably between winters to summer. The minimum temperature records in the study area was 10°c at Assela, Bekoji and Bui stations and the maximum temperature records was 30°c at Langano station in the year 1993-2013. The average mean monthly temperatures of the study are shown in the figure 3-10.

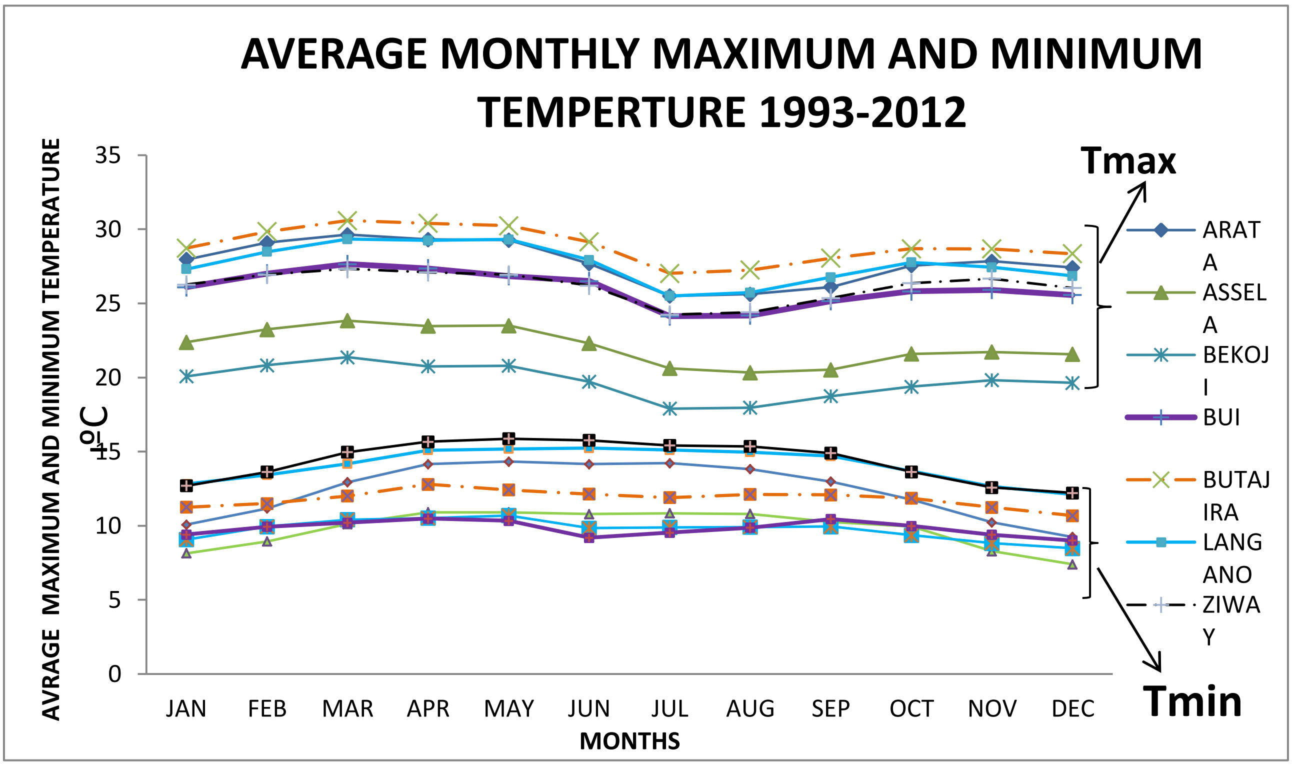



Figure 3-10 Average monthly maximum and minimum temperature 1993-2012

### 3.4.1.1.3 Evaporation

Evaporation is considered from two aspects: evaporation from an open water surface and evapo-transpiration, which is the evaporation of intercepted water and transpiration from vegetation. Knowledge of evaporation is a major importance in water resources assessment among others to determine the amount of water lost through the process of evaporation in the water balance computations of land, rivers, lakes and reservoirs. The amount of water evaporated from a water surface is estimated by the following methods by using evaporimeter data, empirical evaporation equations, and analytical methods. The analytical methods provide better results, they involve parameters that are difficult to assess or expensive to obtain (subramanya, 2008).

In order to compute potential evaporation or reference evapo-transpiration, a number of methodologies are available which include Penman and its modification based type equations like Penman-Monteith, Temperature type equations like; Blanely-Criddle method and Thornthwaite method (Maidment, 1993).

According reported in FAO revised methodology, the Penman- Moteinth equation provides the best method for the evapo-transpiration and evaporation computation. Therefore mean monthly evaporation are estimated based on FAO-CROPWAT 8 program which is based on the penman monteith model. The result is given tabularized in Table 3-3 and Figure 3-11.

**Table 3-3 Mean Monthly Climatic data in study area(1993-2012)**

| Month | Min Temp °C | Max Temp °C | Humidity % | Wind km/day | Sun hours | Rad MJ/m²/day | Eto mm/day | Eto mm/month |
|---|---|---|---|---|---|---|---|---|
| January | 12.7 | 27 | 70 | 2 | 10 | 22.4 | 5.1 | 163.14 |
| February | 13.6 | 28 | 72 | 2 | 9 | 22.2 | 5.1 | 162.32 |
| March | 15 | 29 | 76 | 2 | 9 | 23.3 | 5.7 | 183.23 |
| April | 15.7 | 29 | 73 | 2 | 9 | 23.4 | 5.5 | 165.98 |
| May | 15.9 | 29 | 76 | 2 | 8 | 21.2 | 5.8 | 177.33 |
| June | 15.8 | 28 | 76 | 2 | 8 | 20.7 | 5.4 | 165.33 |
| July | 15.4 | 26 | 77 | 2 | 7 | 19.4 | 4.6 | 140.31 |
| August | 15.3 | 26 | 77 | 2 | 7 | 19.9 | 4.7 | 142.46 |
| September | 14.9 | 27 | 76 | 1 | 7 | 20.1 | 4.6 | 141.16 |
| October | 13.6 | 28 | 66 | 2 | 9 | 22.4 | 5.4 | 164.90 |
| November | 12.6 | 27 | 61 | 2 | 10 | 22.6 | 5.1 | 156.61 |
| December | 12.2 | 27 | 63 | 2 | 9 | 20.5 | 5.1 | 155.18 |
| **Average** | **14.4** | **27.6** | **72** | **2** | **8.5** | **21.5** | **5.19** | **1917.95** |

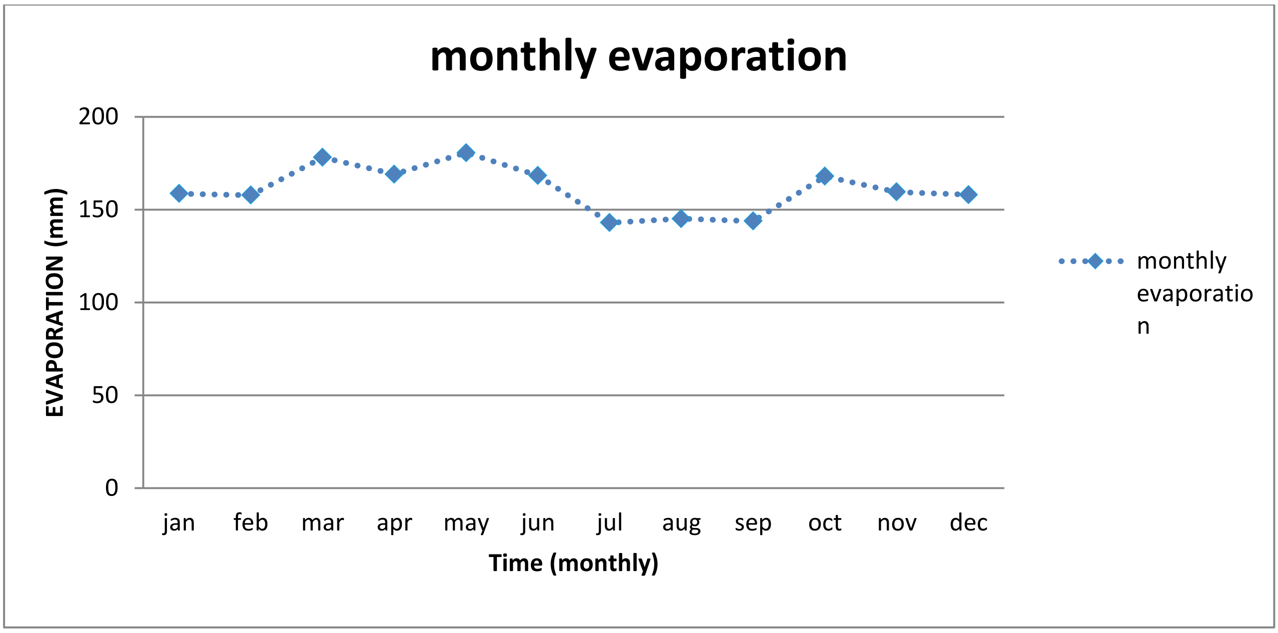



**Figure 3-11 the distribution of mean monthly evaporation for study area from 1993-2012**

### 3.4.2 Hydrological data collection

#### 3.4.2.1 *Water resources of Lake Watershed*

Lake, Katarr, Meki and Bulbula rivers are the major water resources in the watershed. There are also seasonal that originated from highland areas either feeding these major rivers or directly drain to the lake. Measuring devices in all three rivers as well as in the lake are recorded manually on daily basis. The river discharge time series have been collected from MoWIE.

Meki River originates in the Gurage mountains to the west and northwest of the lake. The total river drains an area of 2433 $km^2$ near to Meki town gauging station. River Meki drains the western mountains and escarpments including a vast swampy area to the south of Butajira town (OEPO, 2005).The Katarr River is the biggest perennial river beginning from Arsi highlands of mountains from Cacca and Badda, and drains to the northwest side of the watershed and finally joins to the lake. Because of the steep configuration of the Katarr valley, areas suitable for irrigation are few in number and very limited in extent (Makin, 1976). Therefore, the prime importance of the Katarr River is the contribution to Lake. The river has catchment area of 3350 $km^2$ at

Abura gauging station. The details of the Meki and Katarr River of the study area are described in section in hydro meteorological analysis.

The out flow from Lake is through Bulbula River, which feeds to downstream Lake Abiyata. Bulbula River fall away distance of 30km between Lake Ziwway and abijata, except during the wet season, it is completely dependent on the Lake level, which has resulted in its consecutive drying up during low levels of the lake water depth (OEPO, 2005). During the past three decades, the mean annual discharge of Katarr and Meki rivers contributed by about twice the direct rainfall inputs to the lake or about 15% of annual rainfall of the watershed (Helco, 2007).

### 3.4.2.2 Hydrological data analysis

According to watershed the river data discharge data gathered for three gauging station about 28% the river was screened to identify unreliable or spurious data; screening was done with help of graphical tools some suspicious data and data gaps have been observed. Plotting the river flow data of Meki river shows that the hydrograph of 1996/1997 and 2006/2007 has reading gaps.

The graphical view of Meki River of daily discharge in figure 3-6 shows that the river flow decrease since the rainfall patter of the area doesn't change significantly .In this work it has assumed that spurious are due to measurement error or use of an erroneous.

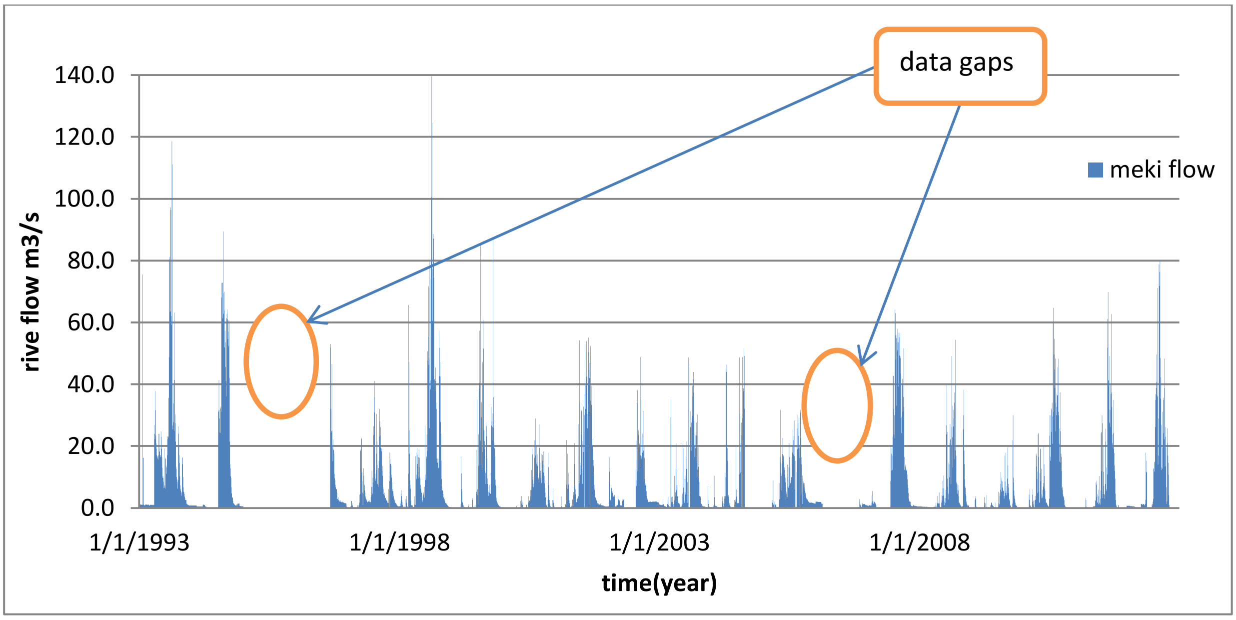



**Figure 3-12 Meki river reading gaps between 1996-1997 and 2006-2007**

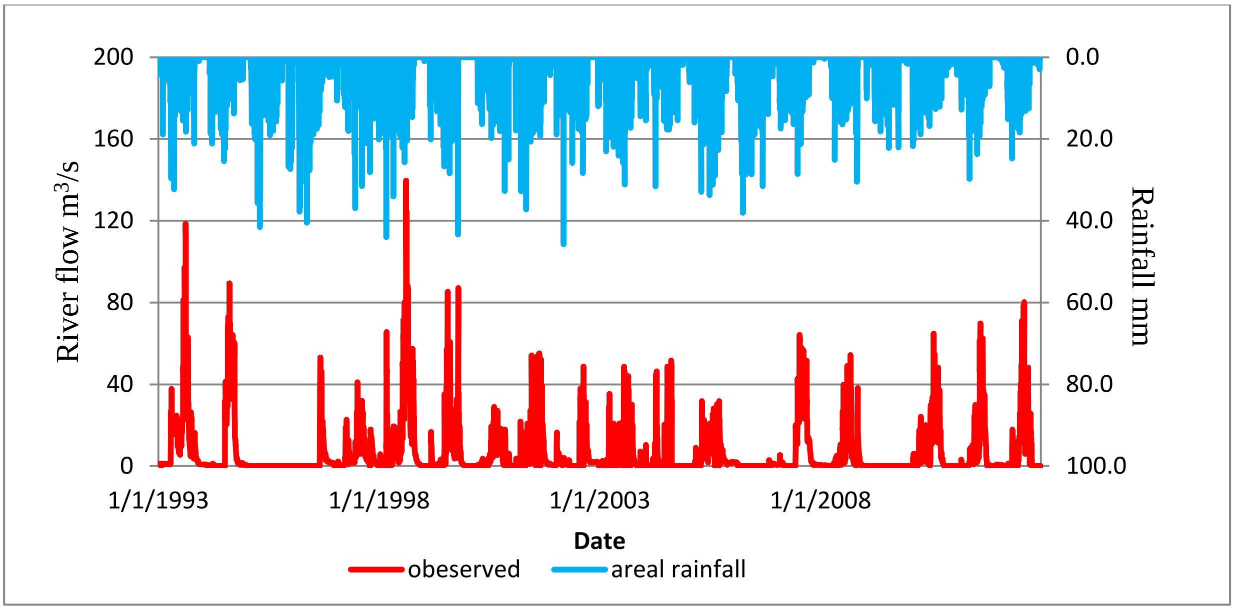



**Figure 3-13 Comparison of river discharge with rainfall data for Meki River**

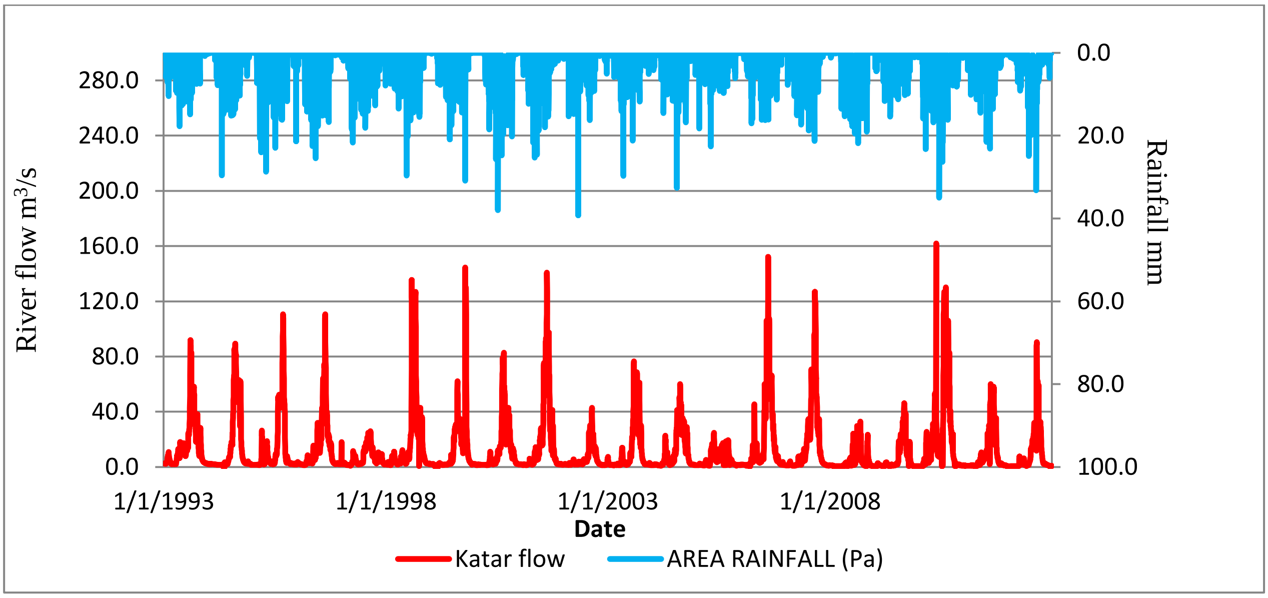



**Figure 3-14 Comparison of river discharge with rainfall data for Katarr river**

## 3.5 Lake Bathymetry and Capacities

Bathymetry is the measurement of the depth of water bodies from the water surface. Some standard techniques to investigate the lake floor are echo sounding, multi-beam sonar, side scan sonar, seismic reflection and, seismic refraction satellite altimetry. Most of the time bathymetric maps are generated by use of an echo sounder which measures the depth of the lake floor.

The first bathymetry survey of Lake is conducted in 1976 by land resources division; ministry of overseas development (Makin M. K., 1976) and ministry of water of water resources 2005/2006 were developed. Using this map the Volume-Area-Elevation relationships of the lake reservoir were assessed and associated curves were recognized. The gauging staff (zero water levels) of the Lake is located at 1635.10masl and the outflow discharge at Bulbula River is measured at 1635.56masl or 0.46m above the staff gauge at town is used in both Bathymetry study. The dead storage of the Lake is the volume below the elevation 1635.56m. Equation 3-2 and 3-3 describes elevation -area and elevation volume respectively.

$$Y = 0.0727x^6 - 1.7613X^5 + 14.953x^4 - 51.945x^3 + 72.74x^2 - 27.401x - 0.6012 with R2 = 0.9973 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3-2}$$

$$Y = -0.1289x^5 + 2.202x^4 - 7.6764x^3 + 3.1549x^2 + 13.673x - 2.3472\ with\ R2 = 0.9996 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots \text{Equation 3-3}$$

.

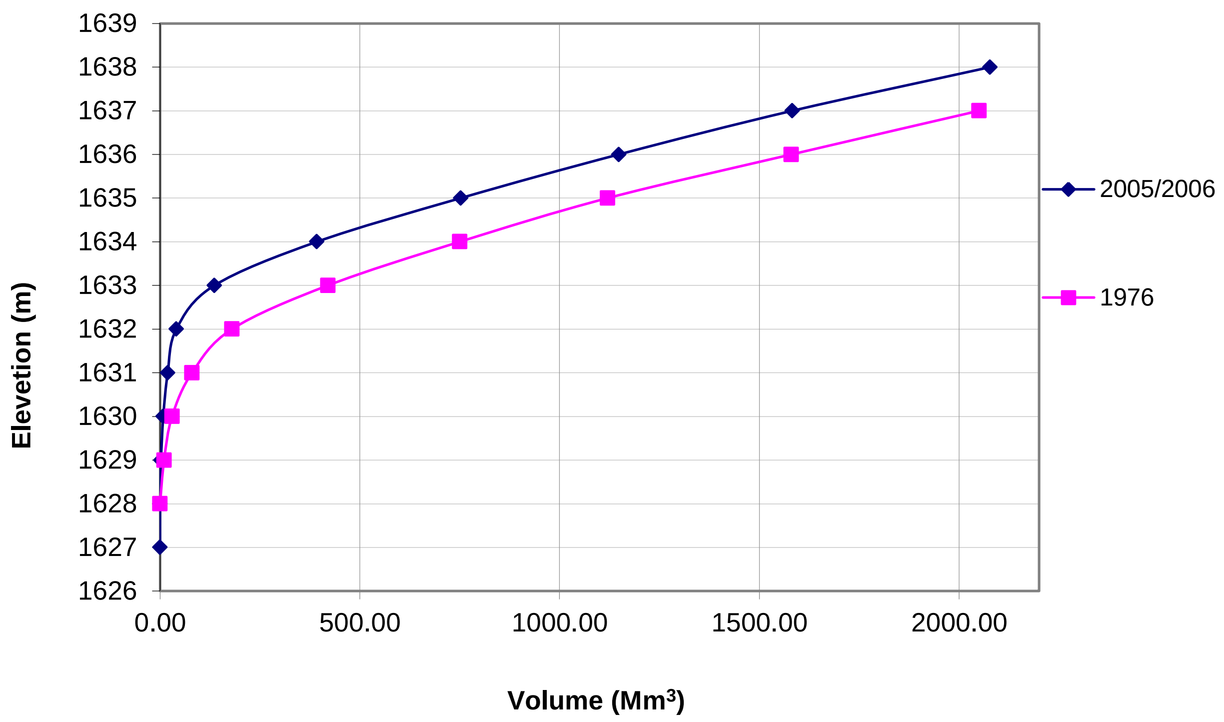



Figure 3-15 Elevation- Volume curve of Lake Ziway

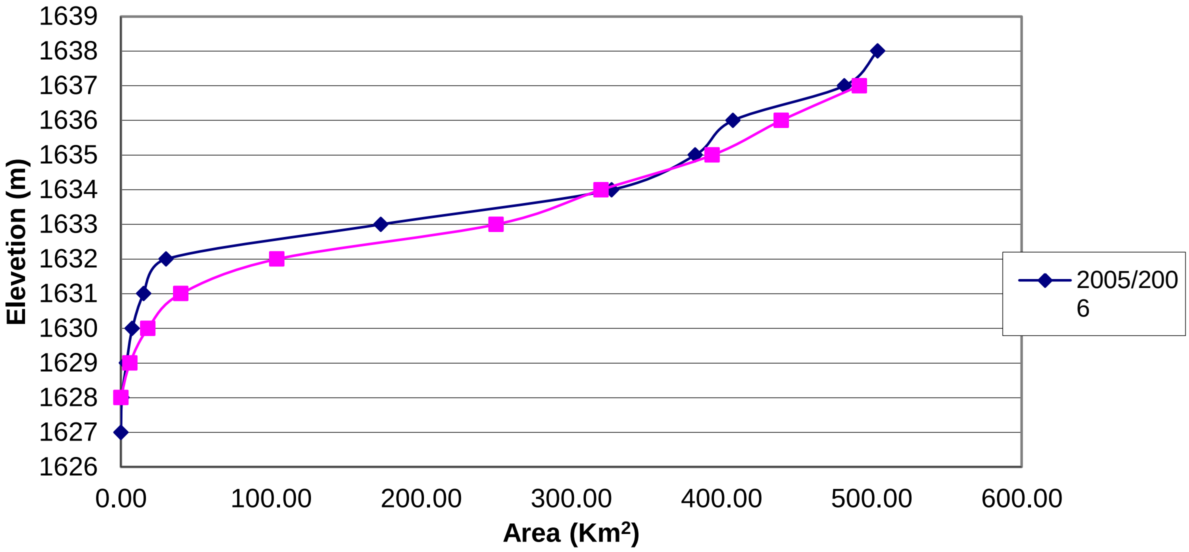



Figure 3-16 Elevation -Area curve of Lake Ziway
*Source: Ministry of Water, Irrigation and Energy*

In this study to simulate the water balance with is done using recent bathymetry survey i.e. by ministry of water resources (2005/2006) on the above equation. According to the figure 3-15 and 3-16 the volume at 1636m was found to be 1203.7 MCM and the area 436.36 km$^2$.

## 3.6 Water Abstraction

The estimation of the water abstraction refers to direct abstraction from surface water and doesn't include abstraction from ground water resources and water use from rainfall. Seeing of water abstraction from rivers is used to find the trend of rivers discharge. According data gathered from different source during data collection commercial farms that produces different floriculture, horticulture and other industries abstracting water from the lake, Katarr and Meki Rivers.

### 3.6.1 Water Abstraction from Katarr Rivers

Large-scale irrigation was started in Katarr sub-basins in mid of 1980's by Katarr irrigation project. Since then, irrigation demand has been increased by using the river and its tributaries. In the highland area potato is the most dominant vegetable while tomato, cabbage, onion and papaya are produce in lowland areas (Dribsa, 2006). About 13.61 Mm$^3$/year are abstracted to irrigate 1127 ha. It was very difficult to get the irrigation data even from the entitled agency due to lack of Compiled data. Estimated monthly variation and water use rate were obtained from the feasibility study for pressurized irrigation (WWDSE, 2008), table1 and table 2 which describe the total land covered by irrigation in the current situation and estimated monthly water abstraction respectively.

### 3.6.2 Water Abstraction from Meki Rivers

Potato, tomato, onion and pepper are dominantly produced in Meki sub-basins. A total of 880 ha of land are under cultivation. Using similar estimation method as mentioned above, the total annual abstraction from the river is about 10.66Mm$^3$/year.

### 3.6.3 Water Abstraction from Lake

Due to its accessibility, favorable location in relation to Addis Ababa and fresh water quality, Lake has been considered the most important water exploitation area in the rift valley (Halcow, 1992).a total land of 4840 ha excluding Sher Ethiopia Flower Farm it has about 500 ha is irrigated using the lake water (WWDSE, 2008)and (source: East Showa Zone and Woreda Agricultural and rural development offices). Using similar estimation method as mentioned above, the total annual abstraction from the Lake is about 79.55Mm3/year.

Estimated monthly variation and water use rate were obtained from the feasibility study for pressurized irrigation (WWDSE, 2008), table1 and table 2 which describe the total land covered by irrigation in the current situation and estimated monthly water abstraction respectively.

Table 3-4 Total land cover and water usage requirement for irrigation around Lake Ziway.

| irrigation scheme | irrigation area in 2004 in ha | annual gross water requirement for 2004 (Mm3) | irrigation area in 2008 in ha | annual gross water requirement for 2008 (Mm3) | irrigation area in 2012in ha | annual gross water requirement (Mm3) |
|---|---|---|---|---|---|---|
| Meki irrigation | 317.7 | 3.8 | 388.0 | 4.7 | 839.0 | 10.1 |
| Katarr irrigation | 466.8 | 5.4 | 856.0 | 9.8 | 1127.5 | 12.9 |
| Ziway irrigation | 2181.1 | 27.7 | 3506.4 | 44.5 | 5840.8 | 74.1 |
| sher ethiopia flower farm | 500.0 | 7.3 | 500.0 | 7.3 | 500.0 | 7.3 |
| Ziway lake water supply | | 0.6 | | 0.6 | | 0.6 |
| **total** | **3,465.55** | **44.78** | **5,250.49** | **66.92** | **8,307.22** | **105.11** |

*Source: OIDA and Agricultural and rural development offices*

**Table 3-5 Estimated Monthly Water Abstraction for Major Irrigation Project (MCM)**

| 2004 condition | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abstraction type | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **annual water requirement in mcm** |
| **Meki river irrigation diversion** | 0.43 | 0.51 | 0.56 | 0.61 | 0.40 | 0.06 | 0.00 | 0.00 | 0.01 | 0.41 | 0.43 | 0.43 | 3.84 |
| **Katarr river irrigation diversion** | 0.60 | 0.71 | 0.78 | 0.86 | 0.56 | 0.08 | 0.00 | 0.00 | 0.01 | 0.57 | 0.60 | 0.60 | 5.37 |
| **Ziway lake pumped irrigation** | 3.10 | 3.65 | 4.04 | 4.43 | 2.88 | 0.42 | 0.00 | 0.00 | 0.06 | 2.93 | 3.10 | 3.10 | 27.71 |
| **Ziway shere flower pumped irrigation** | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 7.27 |
| **Ziway lake pumped water supply** | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.72 |
| total water abstraction in mcm | **4.80** | **5.53** | **6.05** | **6.57** | **4.50** | **1.22** | **0.67** | **0.67** | **0.74** | **4.58** | **4.80** | **4.80** | **44.91** |

| 2008 condition | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Abstraction type** | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual water requirement in mcm |
| **Meki river irrigation diversion** | 0.53 | 0.62 | 0.68 | 0.75 | 0.49 | 0.07 | 0.00 | 0.00 | 0.01 | 0.50 | 0.53 | 0.53 | 4.69 |
| **Katarr river irrigation diversion** | 1.10 | 1.30 | 1.44 | 1.57 | 1.02 | 0.15 | 0.00 | 0.00 | 0.02 | 1.04 | 1.10 | 1.10 | 9.84 |
| **Ziway lake pumped irrigation** | 4.98 | 5.87 | 6.50 | 7.12 | 4.63 | 0.67 | 0.00 | 0.00 | 0.09 | 4.72 | 4.98 | 4.98 | 44.54 |
| **Ziway shere flower pumped irrigation** | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 7.27 |
| **Ziway lake pumped water supply** | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.72 |
| total water abstraction in mcm | **7.28** | **8.46** | **9.28** | **10.11** | **6.80** | **1.55** | **0.67** | **0.67** | **0.78** | **6.92** | **7.28** | **7.28** | **67.07** |

| **2012 condition** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Abstraction type** | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual water requirement in mcm |
| **Meki river irrigation diversion** | 1.14 | 1.34 | 1.48 | 1.62 | 1.05 | 0.15 | 0.00 | 0.00 | 0.02 | 1.07 | 1.14 | 1.14 | 10.15 |
| **Katarr river irrigation diversion** | 1.45 | 1.71 | 1.89 | 2.07 | 1.35 | 0.19 | 0.00 | 0.00 | 0.03 | 1.37 | 1.45 | 1.45 | 12.96 |
| **Ziway lake pumped irrigation** | 8.30 | 9.78 | 10.82 | 11.86 | 7.71 | 1.11 | 0.00 | 0.00 | 0.15 | 7.86 | 8.30 | 8.30 | 74.20 |
| **Ziway shere flower pumped irrigation** | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 7.27 |
| **Ziway lake pumped water supply** | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.72 |
| **total water abstraction in mcm** | 11.55 | 13.50 | 14.86 | 16.22 | 10.78 | 2.12 | 0.67 | 0.67 | 0.86 | 10.97 | 11.55 | 11.55 | 105.30 |

## 3.7 HBV model setup

### 3.7.1 Modeling of the gauged sub basins

As described in chapter 2 the HBV model was used to model the two sub basin of the Ziway watershed. And each sub basin simulated as one district. The name of the district is watershed, with in watershed district created Meki sub basin and Katarr sub basin. Information requires is name and outlet coordinates of the sub basin. From the district, the sub basins were marked as both the principal and presentation basins.

### 3.7.2 Model Parameters

Some of the model parameter values considered from the observed data and most of the parameters provided in a range and they are altered until the optimum values are determined .In calibration 4.1.6 described most of the appropriate value is done.

**Parameter determination from the observed data**

- **Hq**

Hq is a calculated value and it is given in mm.it is calculated in the in the following formula……

$$HQ = \frac{(MQ*MHQ)^{0.5}*86.4}{A} \; or \; HQ = \frac{MHQ*43.2}{A} \ldots\ldots\ldots\ldots\ldots ..\textbf{Equation 3-4}$$

Where:-

MHQ and MQ are mean of the annual peaks and the mean of observed discharge over the whole period respectively. A is area in km2.

The calculated value the sub basin is given in the table below:-

Table 3-6 Calculated Parameters

| *Sub basin* | *Area in $km^2$* | *MHQ* | *HQ* |
|---|---|---|---|
| *Meki* | *2319.5* | *9.57* | *1.09* |
| *Katarr* | *3339.7* | *10.34* | *0.78* |

### 3.7.3 HBV model input

Input data for HBV model are daily rainfall, daily temperature, long term monthly evapotranspiration and daily river flow data for calibration.

**Rainfall**

Precipitation includes rainfall, snowfall, and other processes by which water falls to the land surface (Chow, Maidment, & Mays, 1988). Precipitation data can be used in different ways for water balance calculations. However, this input is subjected to uncertainty as a result of measurement errors, systematic errors in estimation of areal rainfall and stochastic error due to the random nature of rainfall.

A total of eleven rainfall stations within and around Lake are used to estimate the aerial rainfall of each sub basins by using Thiessen polygon method after process of filling and checking the consistency of rainfall time series data. This is the method of interpolation that is used by HBV model (SMHI, 2006). This Thiessen Polygon method gives weight to a point in proportion to the space between the stations. However the method does not take the effect of orography into account and hence this can lead to propagation of uncertainties in the rainfall distribution over the entire area. Figure 3-18 shows the location of the metrological station and their contributions.

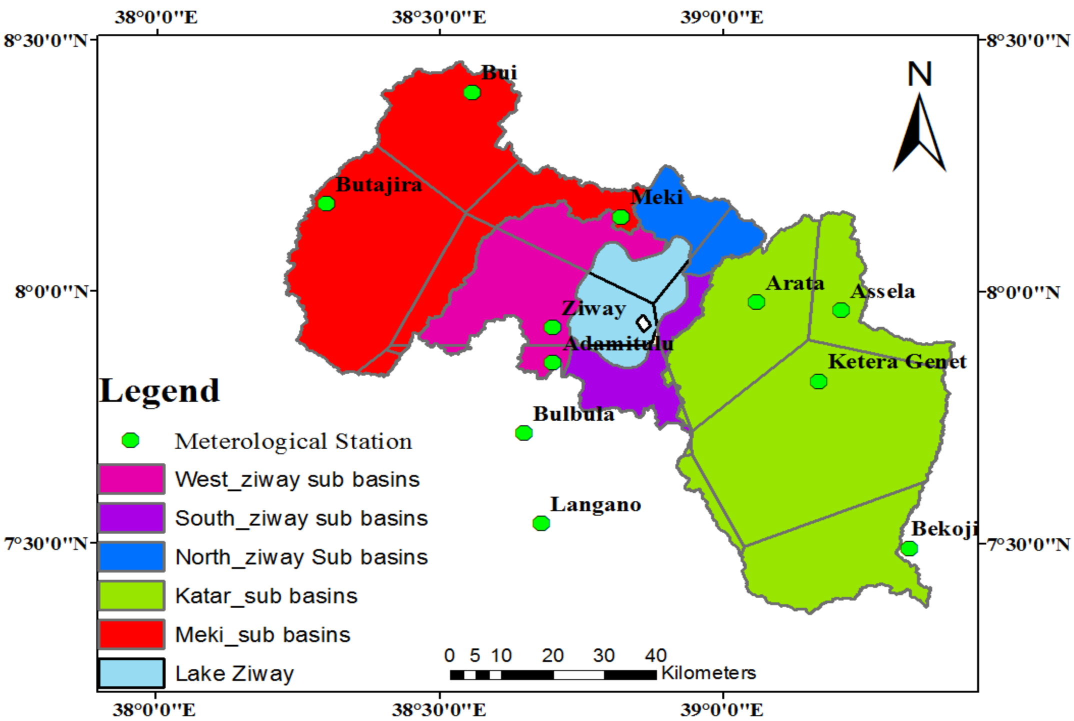



**Figure 3-17 Location of Meteorological station and their contribution**

Table 3-7 Weight of rainfall station by Theison polygon method

| Sub bsins | Bulbula | Bui | Adamitulu | Ziway | Meki | Butajira | Ketra genet | Bekoji | Assela | Arata | Langano |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Meki | 0.01 | 0.28 | 0.00 | 0.08 | 0.12 | 0.50 | | | | | |
| Kater | 0.00 | | 0.00 | | | | 0.46 | 0.18 | 0.11 | 0.23 | 0.02 |
| Lake | | | 0.10 | 0.44 | 0.37 | | | | | 0.09 | |

**Long term monthly Evapotranspiration**

The daily potential Evapo-transpiration for Meki and Katarr was calculated based on Hargreaves-Samani equation. Hargreaves-Samani equation estimation method was selected for its minimum climatic input data requirements.

$$\boldsymbol{ET_0 = C_H R_a (T_{max} - T_{min})^{E_H} - \left(\frac{T_{max}+T_{min}}{2} + C_T\right)} \text{ ... ... ....} \textbf{Equation 3-5}$$

Where:-

- $ET_0$ = Evapotranspiration (mm/day)
- $R_a$ = Extraterrestrial radiation (mm/day)
- $T_{max}$ = daily maximum temperature (°c)
- $T_{min}$ = daily minimum temperature (°c)
- $C_H$ = Empirical Hargreaves coefficient
- $E_H$ = Empirical Hargreaves exponent
- $C_T$ = Empirical Temperature coefficient

The aerial distribution of the evapotranspiration of the gauged sub basin is estimated by using Theison polygon method. And result of daily evaporation converted to long –term monthly in figure 3-19.

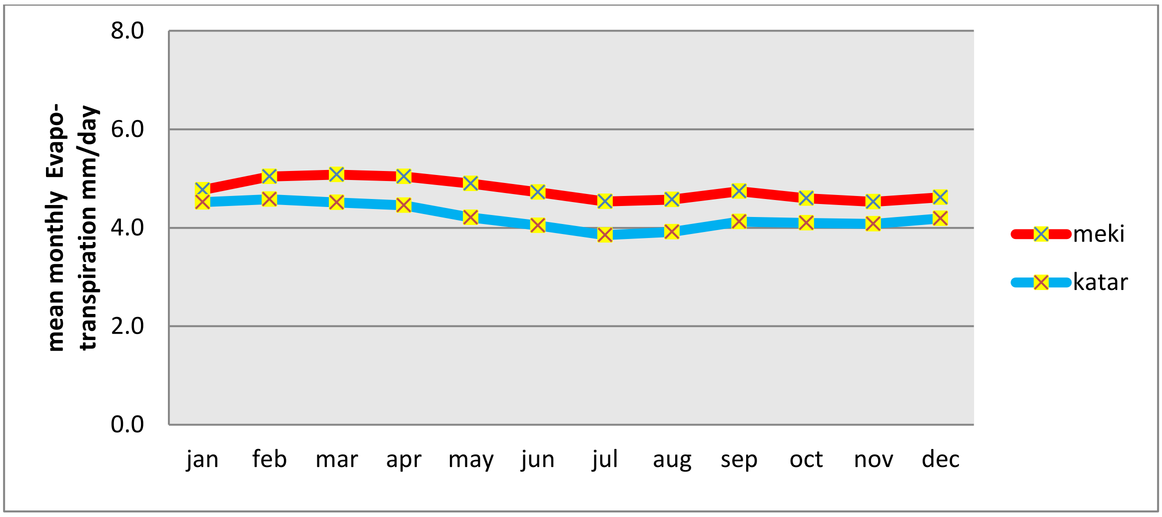



Figure 3-18 Mean Monthly Evapotranspiration of Meki and Katarr subbasin

**Catchment characteristics of gauged catchments (model setup)**

Catchment parameters and geographical zone in HBV model describe as catchment characteristics. A geographical zone represents total area of the catchment, mean elevation (m.a.s.l) and type for the different sub basin zones. Mean elevation of the sub basin were taken from MoWIE. As described in section 2.4, simple classifications of land covers of forest and field (open cover) are required by HBV model (IHMS, 2012).

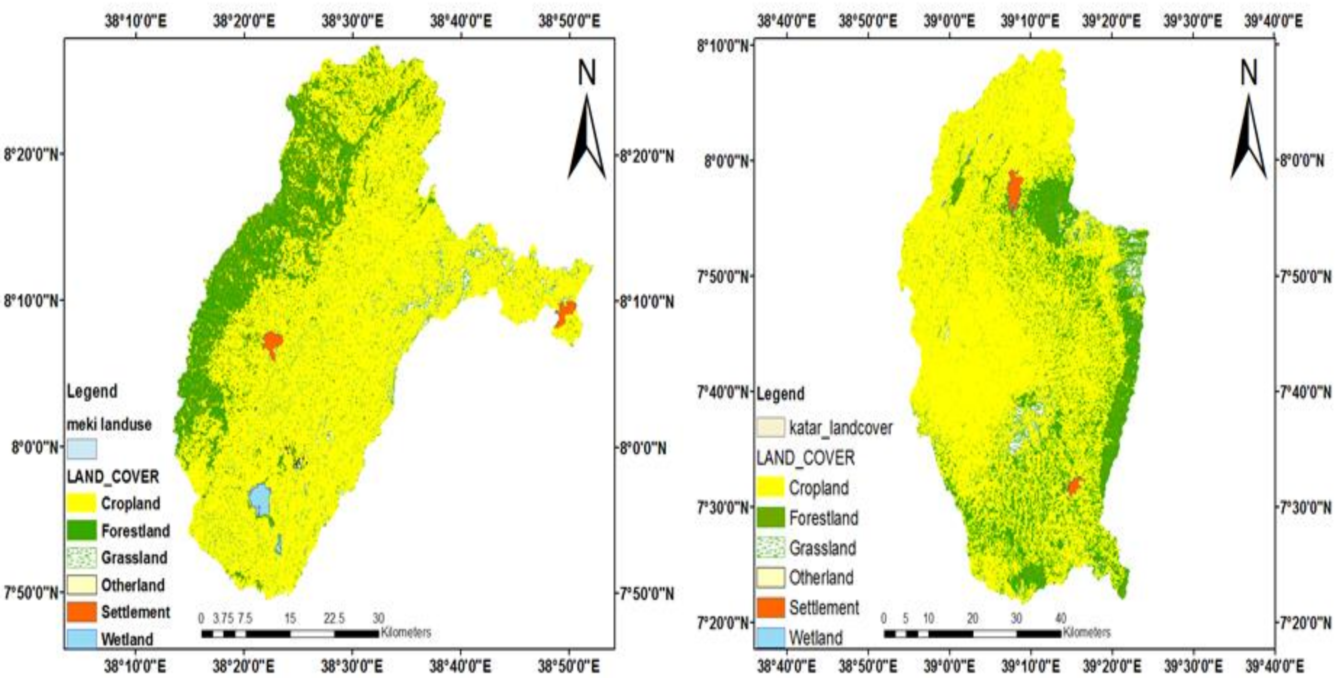



Figure 3-19 Land use/Land cover of Meki and Katarr Sub_basin

Table 3-8 Catchment characteristics for Meki and Katarr Sub basins

| catchment characteristics | Area in km2 | land use/ cover | total are coverage in % | mean elevation | outlets | |
|---|---|---|---|---|---|---|
| | | | | | x | y |
| Meki sub basin | 2319.53 | forest zone with forest | 17.213 | *2750* | *483843* | *899150* |
| | | Field zone without forest | 82.786 | | | |
| Kater sub basin | 3339.68 | forest zone with forest | 18.283 | *2770* | *497797* | *3289.7* |
| | | Field zone without forest | 81.7166 | | | |

As described in section 3.3.3, the land covers of the watershed include six classes. The six land cover classes were aggregated as forest and fields. Figure 3-19 shows the distribution of the two land use classes in each sub basin which the area coverage by class is shown in table 3-6. The model input data are summarized in Table 3-6.

Generally the model calibration and validation periods were selected for this study are as follows;

- Flow Calibration period (1993-2005)
- Flow Validation period (2006-2012)

## 3.8 Lake water balance terms observed data

Inflow to the Lake is the sum of lake areal rainfall, runoff from gauged and un-gauged Sub basins and ground water are the sources of inflow into the lake water balance.

### 3.8.1 Areal rainfall

In figure 3-17 and Table 3-9 it is shows that there are four meteorological stations in and around the Lake. Daily observation from these stations has to be converted to obtain areal coverage by using Thiessen polygon methods.

$$\overline{P} = \frac{\sum_{i=1}^{M} P_I A_I}{A} \text{..............................Equation 3-6}$$

Where

- $\overline{P}$ is areal precipitation in the lake
- A is area of lake in $m^2$
- M is station

Areal rainfall was changed into volumetric terms and calculated using the following equation;

$$\mathrm{P(m^3)} = \frac{\mathrm{P(mm)}*}{1000}\frac{\mathrm{A(m^2)}}{1000000} \text{..........................Equation 3-7}$$

**Where**

- P is a real precipitation in the lake
- A is area of lake in m

### 3.8.2 Surface water inflow from gauged sub basins

Surface water inflow to the Lake includes water by rivers, streams, and direct overland flow. There are two rivers dominating surface water inflow into the lake. In this study HBV model simulation of stream flow is used to Estimation of water balance of the Lake and to see the temporary variation of hydrological change in the Lake.

- River runoff in volumetric terms was considered using the following equation

$$Q = \sum_{n=1}^{30} [(q_1 * 24 * 60 * 60) + (q_2 * 24 * 60 * 60) + (q_n * 24 * 60 * 60)]$$

Where Q is monthly river runoff in $m^3$

- $Q_1$ and q2 to q 30 is daily runoff in $m^3/s$

### 3.8.3 Ground water inflow and outflow

The effects of ground water no significant evidence in the lake (Tenalem Ayenew, 2004). This water balance is determined to model the effect of ground water. The method applied to quantify the ground water component was to model the water balance during dry periods. The runoff is the sum of surface runoff and ground water flow, when surface runoff becomes zero for un-gauged sub basins, the runoff is the sum of runoff from gauged sub basins and ground water flow. In this case the equation to solve for ground outflow becomes;

$$\boldsymbol{Gout = \Delta storage - (Qin - Qout) - E - Ab} \text{..............} \textbf{Equation 3-8}$$

Where

- $\Delta storage$:-is change in storage in $m^3$, $E$ is open water evaporation of the lake in $m^3$, $Q$ is outflow from the lake in $m^3$, $Qin - Qout$ is inflow and outflow in $m^3$ and $Ab$ is abstraction of water for irrigation in $m^3$.

The hypothesis to prove or reject was the effect of outflow from the lake was constant ($\Delta G \approx 0$) when they quantified during the dry period, they were going to made constant therefore it was going to be possible to solve for the runoff from the un-gauged sub basins and try to calibrate the model with the artificially created runoff measured from the un-gauged sub basins.

### 3.8.4 Open water evaporation

The main factors influencing evaporation from open water surface are the supply of heat for vaporization and the process to transport vapor away from the evaporative surface. Influencing factors are solar radiation, wind speed and humidity in the air above open water surface (Chow, Maidment, & Mays, 1988). Evaporation is major component of the Lake water balance, but it is difficult to estimate and has rarely been measured directly.

In this study the penman method was applied which is widely used as the standard method in hydrological engineering applications to estimate potential evaporation from the open water under varying locations and climatic conditions. In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatic records of daily sunshine hours, temperature, humidity, altitude and wind speed.

$$\boldsymbol{E_p = \frac{\Delta}{\Delta+\gamma} * (R_n + A_h) + \frac{\gamma}{\Delta+\gamma} * \frac{6.43*(1+0.536U_2)*D}{\lambda}} \text{......................} \textbf{Equation 3-9}$$

Where:

- $E_p$ is potential evaporation that occurs from free water evaporation (mm/day), $R_n$ is net radiation exchange for the free water surface (mm/day), $A_h$ is energy a dvected to the water body(mm/day), $U_2$ is wind speed measured at 2m (m/s), D is average vapor pressure deficit (kpa), λ is latent heat of vaporization (MJ/kg), ϒ is psychrometric constant (kpa/°c), Δ is slope of saturation vapor pressure curve at air temperature (kpa/°c) (Maidment, 1993)

### 3.8.5 Surface water inflow from un-gauged sub basins

An un-gauged sub basins has scarce of records (in terms of both quantity and quality) of hydrological observation to enable computation of hydrological variables at the appropriate spatial and temporal scales, and to the accuracy acceptable for practical applications (Sivapalan, 2003). These un-gauged sub basins refer to sub basins having topographic and climatic properties that are available without observed data.

Out of the total 5 sub-basins in the study are 3 of them are un-gauged sub-basins which represents a total area of 1212 $km^2$. The un-gauged sub basins are found in north south and west sub basins see figure 3-17.

The regression method is the most widely used regionalization technique but alternative methods are available. The choice of catchments from which information is to be transferred is usually based on catchment characteristics (e.g, soil, land use, climate and topography) similarity measure, i.e. one tends to choose those catchments that are most similar to the site of interest. Calibrated parameters were transferred to the un-gauged catchments. Model parameters of un-gauged catchments are carried out by spatial proximity.

### 3.8.6 Spatial proximity:

Parameters of gauged catchments are transferred to the nearby un-gauged catchments based on the rationale that catchments that are close to each other will have a similar runoff regime as climate and catchment conditions will only vary smoothly in space (Merz, R and G. Bloschl, 2004). Vandewiele and Elias (1995) used a similar approach to estimate parameters of monthly water balance model for 75 catchments from neighboring catchments. In this approach the complete set of model parameters is usually transferred from one or more gauged catchments to un-gauged catchments, while in the regression the parameters are regionalized independently from each other. In this study parameter values derived for gauged catchment in upstream areas were transferred to downstream areas of un-gauged catchment. Figure 3-20 shows the catchment relation layout based on the spatial proximity method.

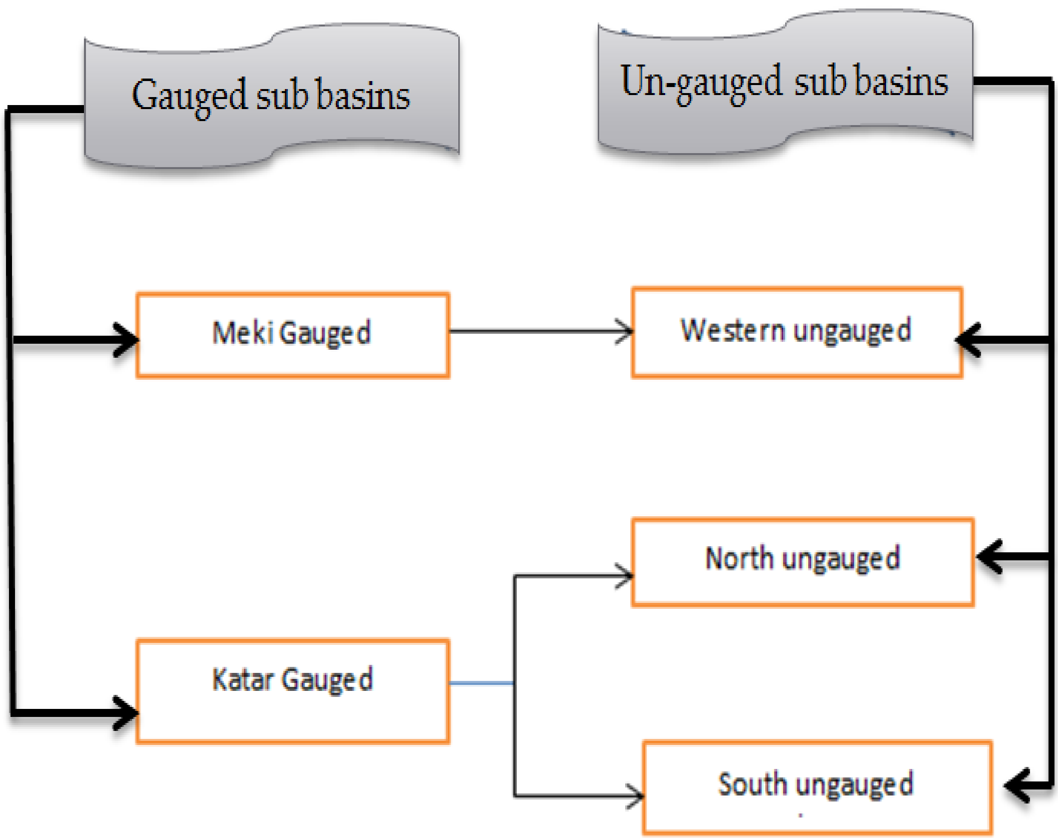



Figure 3-20 catchment relation layouts in spatial proximity method

### 3.8.7 Lake levels and change in storage

Lake level in the Lake are recorded daily. For modeling, monthly averaged lake level values were used. Corresponding to capacities was intended from elevation -area and elevation volume equation described in section 3.5 and figures 3-15 and 1-16.

# CHAPTER FOUR

# 4 RESULT AND DISCUSSION

## 4.1 Water Balance Modeling Lake Ziway

### 4.1.1 General

HBV model was calibrated and validated in the gauged sub-basins of Meki and Katar and the hydrological components of these Sub-basins were estimated accordingly. Next, optimum calibrated parameters from theses Sub-basins were transferred using proximity method to model the flows from un-gauged sub-basins. Finally, the water balance of the lake was calculated in excel spread sheets.

### 4.1.2 Modeling of the gauged sub basins

As described in chapter 2 and chapter 3 the HBV model was used to model the two sub basin of the Ziway watershed. And each sub basin simulated as one district. The name of the district is Ziway watershed, with in Ziway watershed district created Meki sub basin and Katarr sub basin. Information requires is name and outlet coordinates of the sub basin. From the district, the sub basins were marked as both the principal and presentation basins.

### 4.1.3 Initial model results

The HBV model was set up and run on daily time basis. The initial run was conducted for 20 years, from 1993 to 2012 with a two years warm up period. The initial simulated stream flow results were compared with measured stream flow See appendix 4. The comparison was done for each year.

### 4.1.4 Model calibration

After simulated the runoff with initial input data, it was seen that the hydrographs of the simulated flows were not fit with the observed data. This is because the hydrological models ranging from parsimonious lumped to complex distributed physically based models needs to be calibrated (IHMS, 2012). The agreement between .observed and simulated flows should be improved by adjusting the model parameter values through calibration process.

The next thirteen years data (1993-2005) were used for model calibration. Calibrated model parameters were further validated using an independent datasets from 2006-

2012. During model calibration the result of each parameter was observed and was altered until the maximum value was determined. Table 4-1 and 4-2 shows calibrated model parameters and performance of the model measured by the objective function that described in section 2.5.5 respectively.

Table 4-1 calibrated model parameters from 1993-2005

| parameters | Default | Range to change | Adjusted value for Meki | Adjusted value for Katarr |
|---|---|---|---|---|
| Fc | 200 | 100-1500 | 864 | 395 |
| Lp | 0.9 | <= 1 | 0.8 | 0.82 |
| Beta | 2.5 | 42739 | 2.76 | 3 |
| Alfa | 0.6 | 0-1.5 | 0.15 | 0.19 |
| Cflux | 0.5 | 0-2 | 0.1 | 0.002 |
| K4 | 0.01 | 0.001-0.1 | 0.001 | 0.0017 |
| Khq | 0.1 | 0.005-0.5 | 0.1 | 0.075 |
| Perc | 0.5 | 0.01-6 | 0.02 | 0.1 |
| Maxbaz | 0.5 | 0-7 | 4.4 | 4.5 |
| Hq | calculated value | | 1.09 | 0.78 |

**Table 4-2 model performance during calibration**

| Column1 | Meki | Katarr |
|---|---|---|
| Ns | 0.80549 | 0.7996 |
| RVE | -0.0271 | 0.00286 |
| ME | 0.32883 | 0.32476 |

### 4.1.5 Model Validation

The model doesn’t precisely represent the real world system behavior despite that fact that optimal and calibrated model parameters are used (Rientjes, T.H., 2007). Validation is a process of tested model parameters against another independent set of stress conditions; in this particular study validation data of 2006 to 2012 are used for Katar and Meki sub basin.

The objective function used to measure the reliability of the models. These objective functions are available in HBV model is working for analysis the validity of the modeling of Ziway watershed with HBV model.

**Table 4-3 model performance during validation period**

| Column1 | Meki | Katarr |
|---|---|---|
| Ns | 0.74763 | 0.72875 |
| RVE | 0.05917 | 0.03538 |
| ME | 0.44382 | 0.36871 |

The model performance was well accepted based on the hydrograph and statistical evaluation techniques. The observed runoffs in the two gauged sub basins were well represented by the predicted runoff from the model. Both calibration and validation results indicate that a strong relationship between the simulated and observed runoff from the two gauged sub basins. However, some of the extreme events such as peak flow were observed to be underestimated by the model.

The best results with objective function of model were gain from calibration period than validation period for both sub basins and the result are indicate in the above table 4-2 and 4-3. Figure 4-1with Figure 4-4 shows the observed and simulated runoff for Meki and Katarr sub basin during calibration and validation periods.

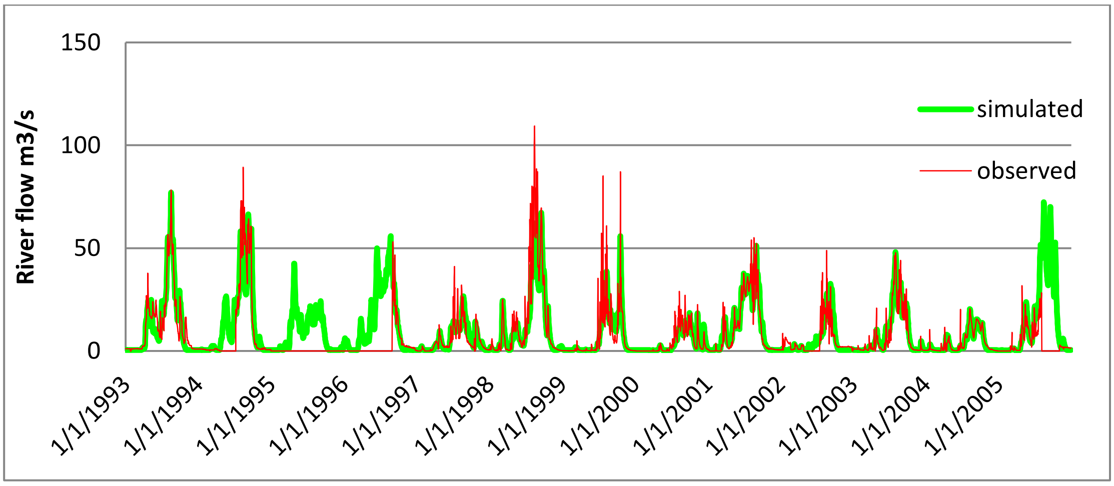



Figure 4-1 model calibration results for Meki subbbasin (1993-2005)

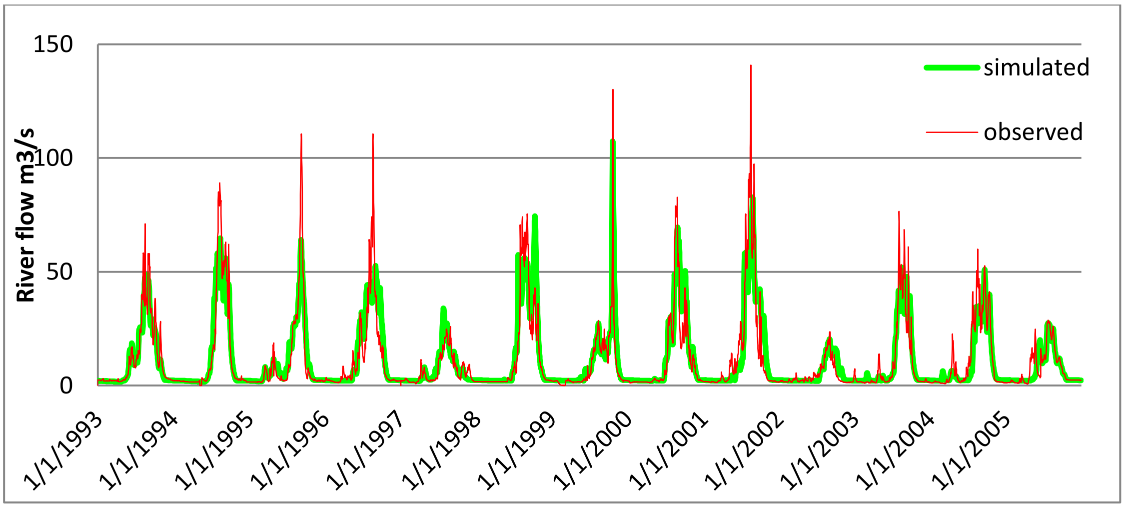



Figure 4-2 model calibration results for Katarr subbsin (1993-2005)

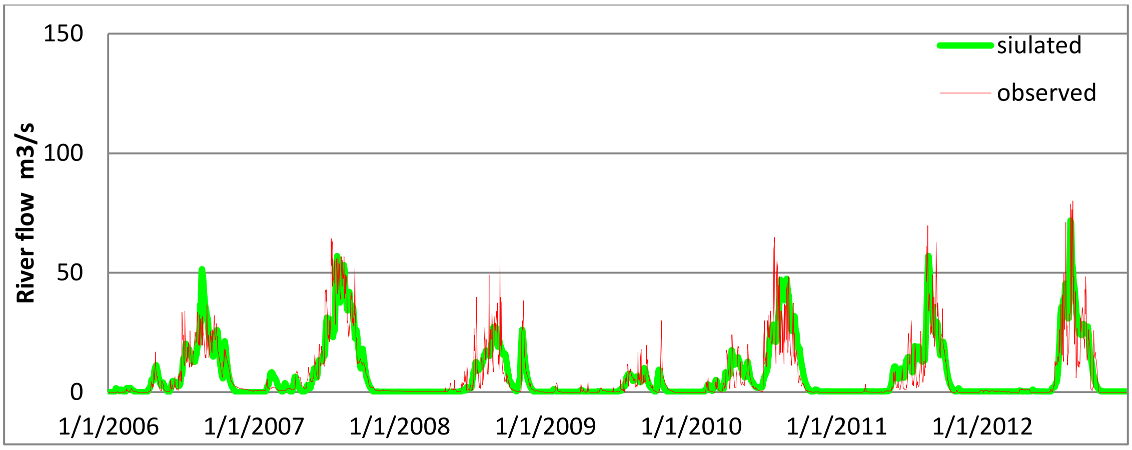



Figure 4-3 model validation results for Meki subbasin (2006-2012)

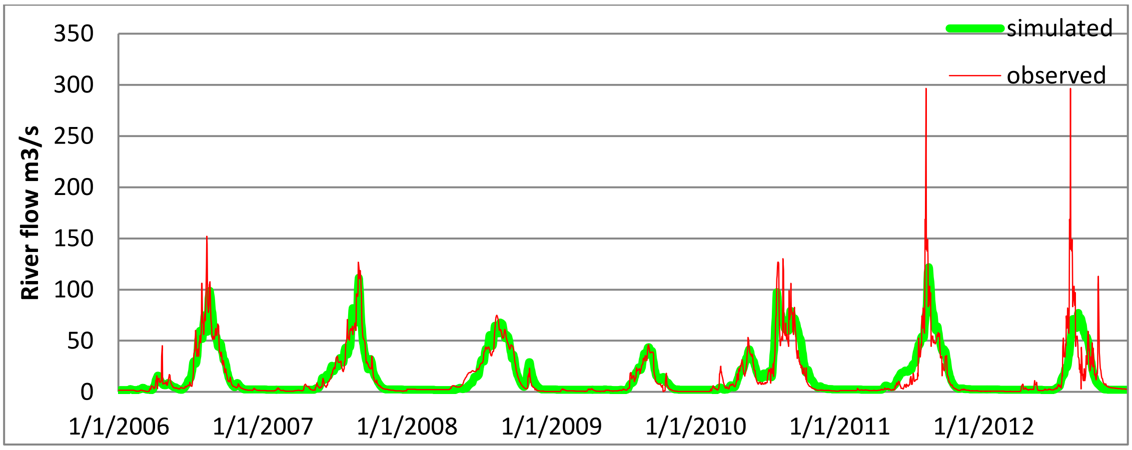



Figure 4-4model validation results for Katarr subbasin (2006-2012)

During the validation period, high correlation between observed and simulated runoff of with $R^2$ =0.9482 for Meki sub basin and $R^2$ =0.9138 for Katarr sub basin were observed Figure 4-5 with Figure 4-8 shows the regression analysis between observed and simulated runoff for Meki and Katarr sub basin during calibration and validation periods.

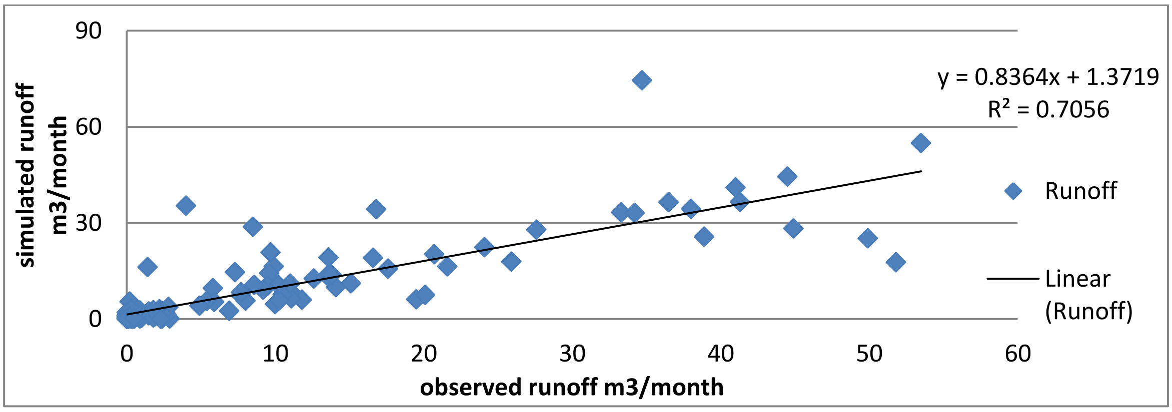



**Figure 4-5 correlation between observed and simulated runoff for calibration period of Meki sub basin**

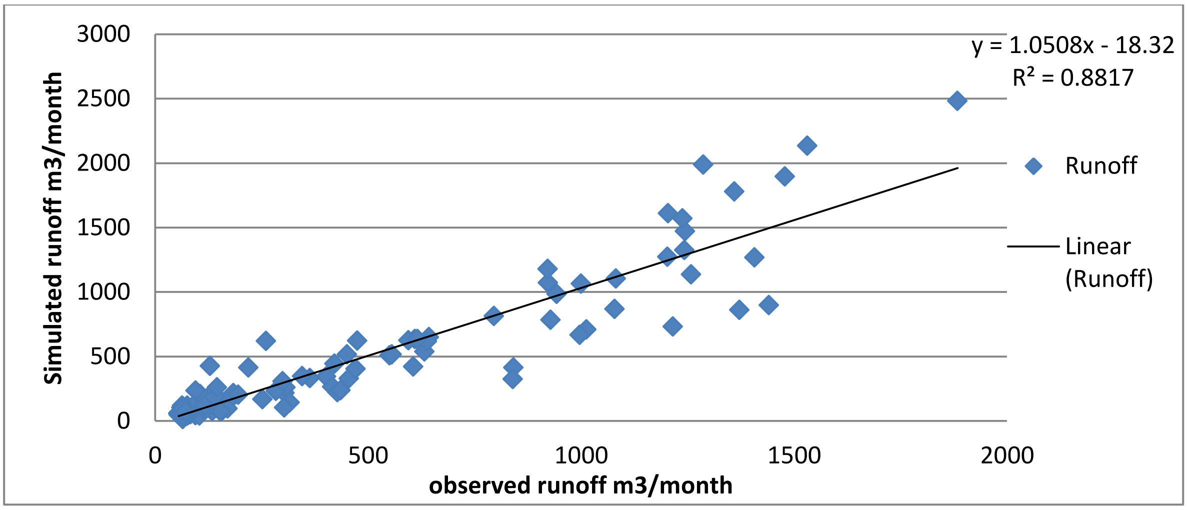



**Figure 4-6 correlations between observed and simulated runoff for calibration period of Katarr sub basin**

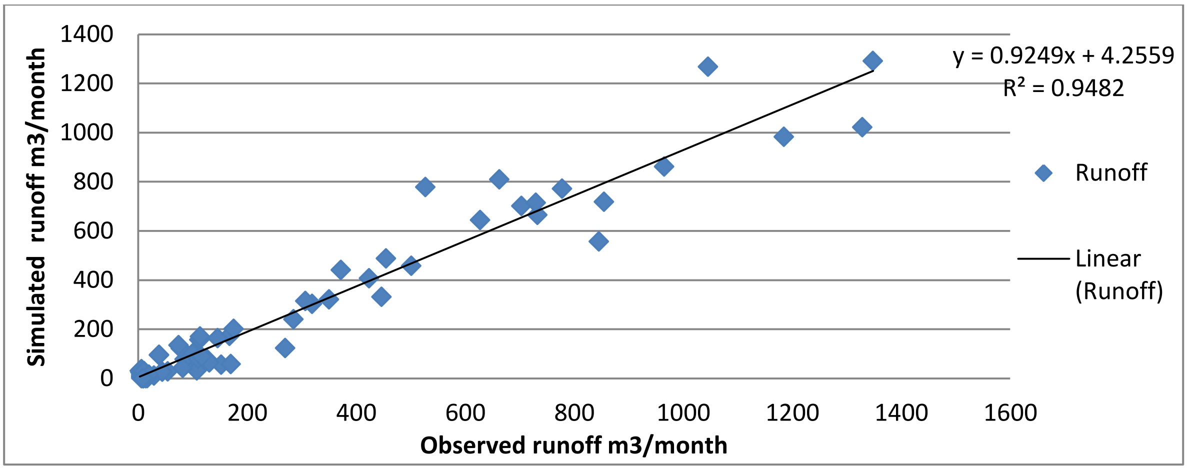



Figure 4-7 correlations between simulated and observed runoff for validation period of Mek

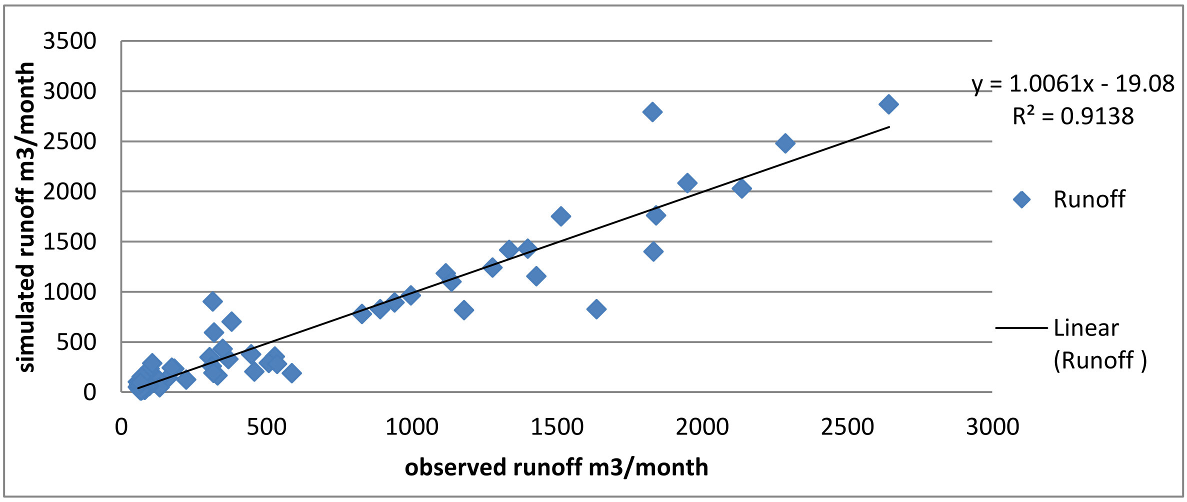



Figure 4-8 correlations between simulated and observed runoff for validation period of Katarr subbasin

In the above Figure 4-5 with Figure 4-8 shows that in some year the simulated runoff could not fit the observed hydrograph due to number of possible factors. In the study area a number of borehole abstractions and surface abstraction along the streams which could not be accounted in the model, hence free model parameters were altered to reduce total runoff from these Sub basins. These parameters cannot effectively account for that water going out of the system.

Besides some input data carried with them errors as well, areal distribution of rainfall for Sub basins was carried by using a Theissen polygon interpolation method using rainfall records from 11 metrological stations. Therefore overestimation and underestimation of point rainfall from one point to the other point is most possible. Evapotranspiration was calculated by using daily temperature data for 7 metrological stations in and around sub basin. The areal distribution of potential evapotranspiration of Sub basins carried out by Theissen polygon interpolation method. Therefore errors could have also been the come upon during the interchange of water particles into vapor by the formula since other factors such as that humidity, wind were not taken into account. Therefore interpolation of this evapotranspiration over the whole area can also cause some gaps.

Finally, hydrological modeling on its own is a simplified representation of the physical hydrological process of the earth but some limitations can be met.

## 4.2 Modeling of the un-gauged sub basins

To estimate inflow from un-gauged sub basins calibrated model parameters from gauged sub basins were transferred by spatial proximity method described in section 3.8.6.

**Table 4-4 Model parameters transfer from gauged catchments to un-gauged**

| catchments | north | south | western |
|---|---|---|---|
| *alfa* | 0.19 | 0.19 | 0.15 |
| *beta* | 3 | 3 | 2.76 |
| *cflux* | 0.002 | 0.002 | 0.1 |
| *fc* | 395 | 395 | 864 |
| *hq* | 0.78 | 0.78 | 1.09 |
| *k4* | 0.0017 | 0.0017 | 0.001 |
| *khq* | 0.075 | 0.075 | 0.1 |
| *lp* | 0.82 | 0.82 | 0.8 |
| *maxbaz* | 4.5 | 4.5 | 4.4 |
| *perc* | 0.1 | 0.1 | 0.02 |

From the modeling outcomes of three un-gauged catchments, the north , south and western, it was seen that during the dry seasons as contrasting the two gauged catchments there is a little or no flow from those un-gauged catchments. This can be real scenario on the ground since the tributary is not a perennial river therefore the modeling results can closer to the truth during dry period. The period of the wet seasons for south un-gauged catchments seen that uncertainty during the period of 2006-2012. Hence, there is no data for calibration as a result in the wet period there is much uncertainty. Figure 4-11, Figure 4-12, Figure 4-13 and Figure 4-14 shows the mean monthly hydrograph of the three un-gauged catchments and the hydrograph of the simulated runoff during the period of 2004-2008. The hydrograph of the whole period are attached in appendix 4.

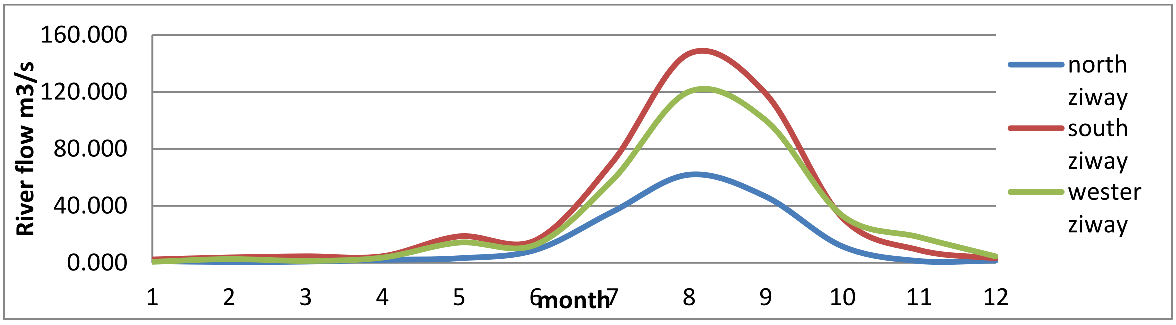



**Figure 4-9 Mean monthly runoff of un-gauged catchemnts**

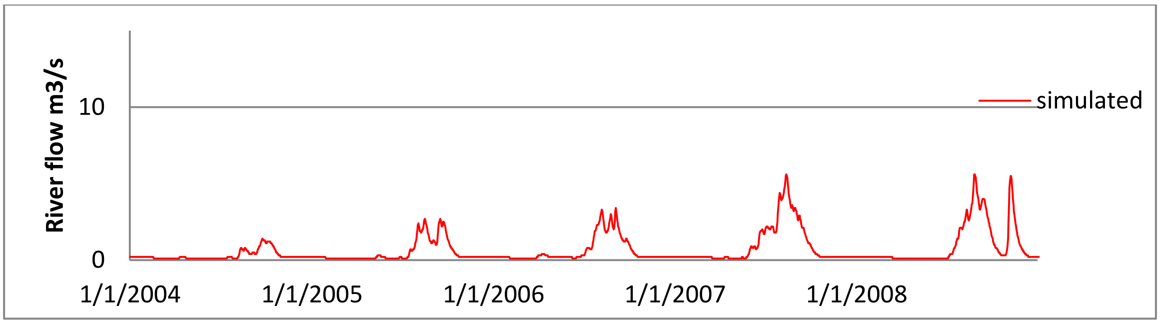



Figure 4-10 Hydrograph of simulated runoff for north subbasin (2004-2008)

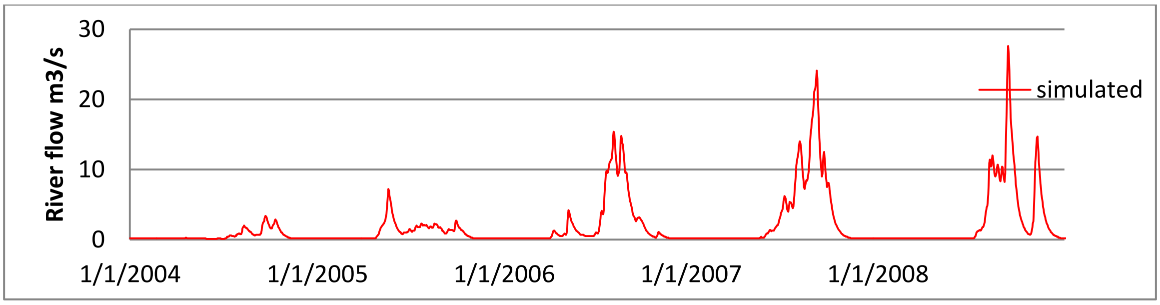



Figure 4-11Hydrograph of simulated runoff for south subasin(2004-2008)

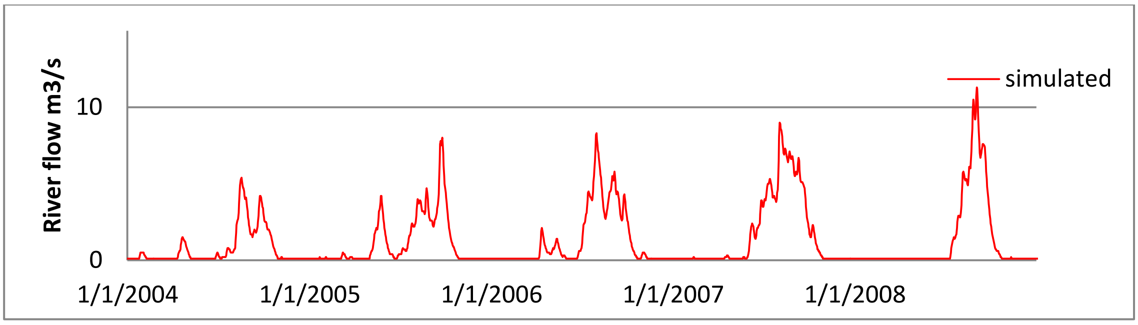



Figure 4-12Hydrograph of simulated runoff for wester  subbasin (2004-2008)

## 4.3 Lake areal rainfall

As described in section 3.8.1 the daily observation from four stations has to be converted to obtain areal coverage by using Thiessen polygon methods.

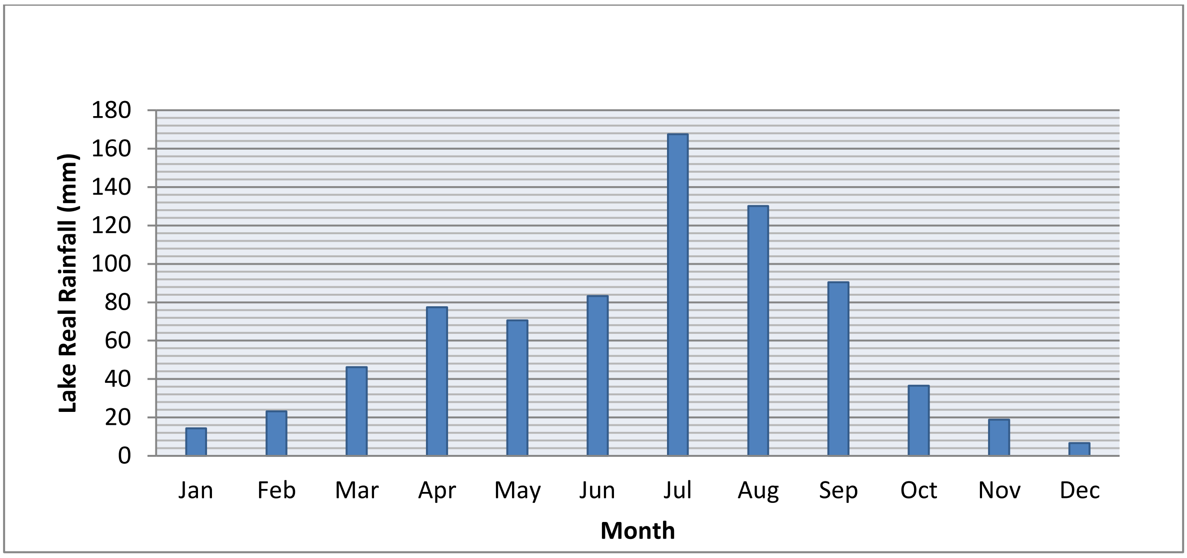



**Figure 4-13Long term mean monthly areal rainfall on the lake Ziway (1993-2012)**

## 4.4 Out flow and lake level relation

Lake Outflow from Bulbula River is converted to volumetric terms like inflow converted in the above section 3.8.5. Some month during the modeling period do not have data and the gaps were filled with long term monthly average. From the series of the observed lake outflow for each month an average value was intended and this was used to fill in the gap for the particular month. Nevertheless the gap filling can be under or over estimated. Generally, the way at which water is flow during the months of the same seasons seems to be the same.

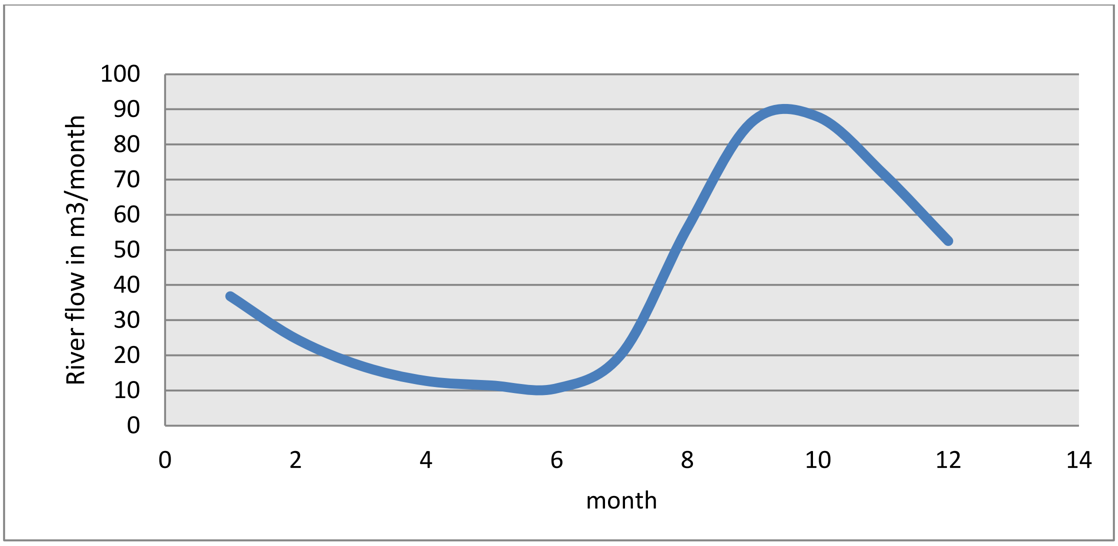



Figure 4-14 mean monthly outflow flow from Bulbula river (1993-2012)

- The only unknown is ground water outflow

## 4.5 Results of Lake Water balance

The result from table 4-9 is the volume water inflowing the lake does not match the change in storage without considering extreme losses during dry period and gaining to during the wet season into the water balance.

Table 4-5 Long term mean monthly water balance of Lake (1993-2012)

| | Monthly inflow (mm) | | | | | | Monthly out flow (mm) | | | change in storage |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | un gauged sub basins | | | | | | |
| month | PPT | Katar | Meki | north | south | west | outflow | Evap | Abs | |
| Jan | 14 | 14 | 4 | 1 | 1 | 1 | 37 | 163 | 17 | -182 |
| Feb | 23 | 13 | 4 | 1 | 2 | 1 | 25 | 162 | 20 | -163 |
| Mar | 46 | 21 | 12 | 1 | 2 | 1 | 17 | 183 | 22 | -139 |
| Apr | 77 | 25 | 24 | 1 | 2 | 1 | 13 | 166 | 24 | -72 |
| May | 71 | 29 | 40 | 1 | 4 | 3 | 11 | 177 | 16 | -57 |
| Jun | 83 | 48 | 41 | 2 | 3 | 2 | 11 | 165 | 3 | 0 |
| Jul | 168 | 138 | 107 | 7 | 14 | 11 | 21 | 140 | 1 | 283 |
| Aug | 130 | 269 | 181 | 12 | 29 | 23 | 56 | 142 | 1 | 445 |
| Sep | 90 | 219 | 137 | 9 | 23 | 19 | 87 | 141 | 1 | 269 |
| Oct | 37 | 102 | 50 | 4 | 8 | 8 | 88 | 165 | 16 | -59 |
| Nov | 19 | 29 | 12 | 2 | 4 | 2 | 72 | 157 | 17 | -179 |
| Dec | 7 | 15 | 4 | 1 | 1 | 1 | 53 | 155 | 17 | -195 |
| yearly (mm) | 765 | 920 | 615 | 43 | 92 | 73 | 489 | 1918 | 152 | -49 |
| Yearly (MCM) | 337 | 405 | 271 | 19 | 41 | 32 | 215 | 844 | 67 | -22 |

PPT, UN-gauged Sub basins, Evap and Abs stands for mean monthly areal rainfall, inflow from un-gauged sub basins, open water evaporation and abstraction from the Lake respectively

The contribution of from direct areal rainfall, Katar River, Meki River and inflow from un-gauged sub basins in percent is 30.49%, 36.68%, 24.52% and 8.3% respectively whereas evaporation loss, outflow to Bulbula River and water Abstraction founded about 74.95%, 19.10% and 5.94%.

**Ground water inflow and outflow**

The hypothesis to prove or reject was the effect of outflow from the lake was constant ($\Delta G \approx 0$) when they quantified during the dry period. The volume water inflowing the lake does not match the change in storage without considering extreme losses during dry period and gaining to during the wet season into the water balance (table 4-5). The result was rejection of the hypothesis meanwhile ground effect was not constant. Ground water varied during each period, figure 34 described the effect ground water varied for the dry period from 1993-2015.

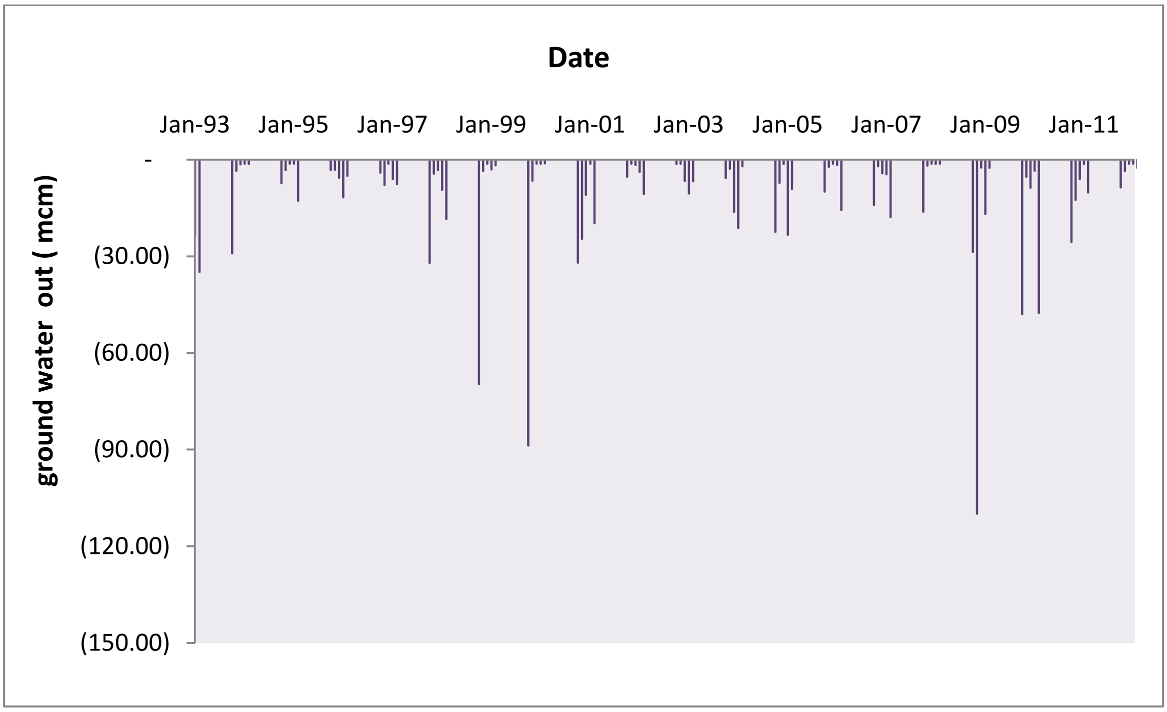



Table 4-6 Long term mean monthly water balance of Lake (1993-201)

In this water balance, even if the runoff contribution from un-gauged sub basins when comparing to the two gauged sub basins is insignificant , still there is amount of water is not accounted for by the know inflow and outflow components. The annual water balance is tabulated on table 4-10 and presented in figure 4-20, the lake water balance has an error of -21.77 MCM/year discharges from the lake to the surrounding, with the lake release or there is significant movement of ground water affecting the lake volume. As described in section 3.6.3 the quality of the lake releases data on the abstraction of water around the lake could not be assessed. In this case if the lake releases at the out let, evaporation, rainfall, runoff from gauging station and change in volume are correct the remaining component is accounted for by ground water. Figure 4-15 shows the residual volume of water in the lake water balance

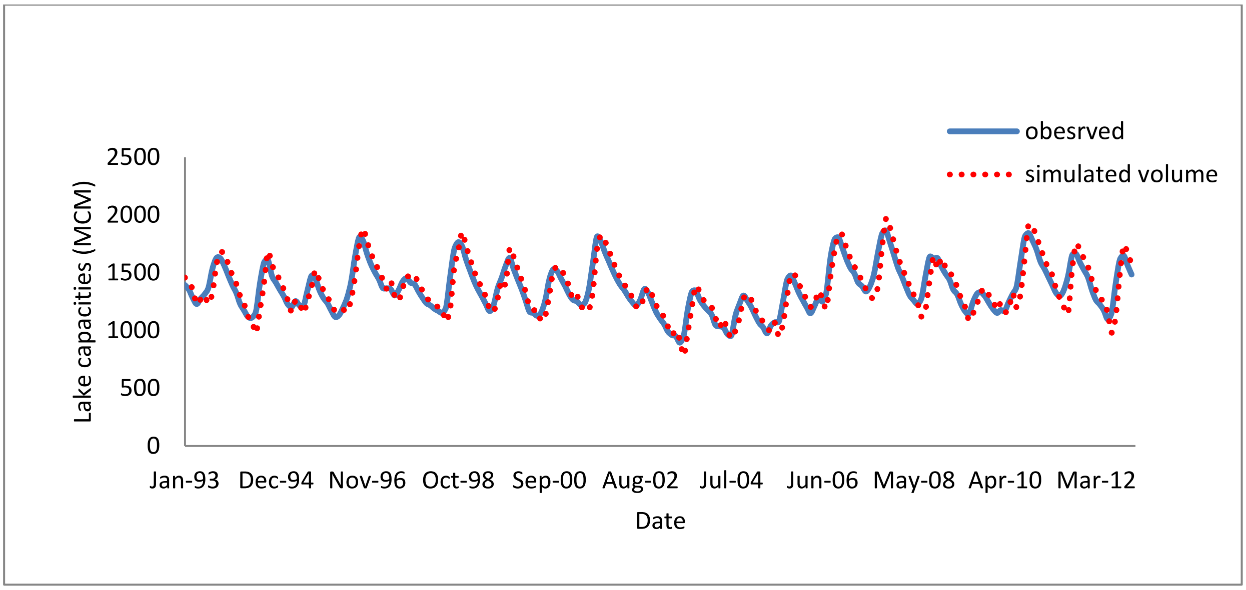



Figure 4-15 observed and simulated Lake capacities for Lake for the period of 1993-2012

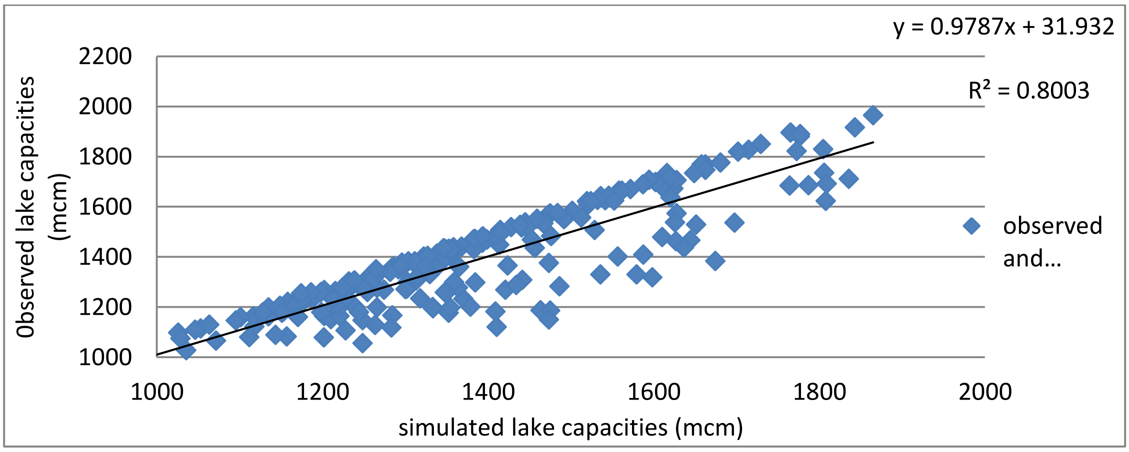



Figure 4-16 scatter plot of observed verse simulated lake capacities

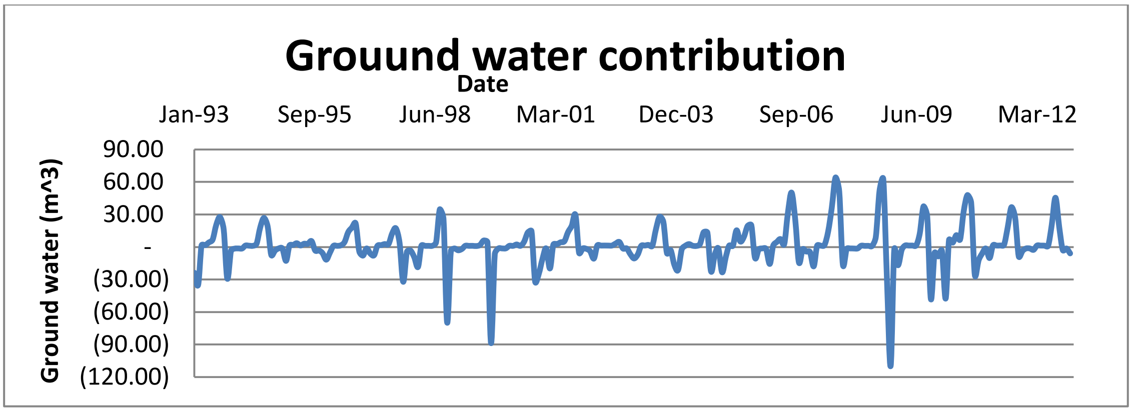



Figure 4-17 residual volume of water in the lake water balance

### Table 4-7 Mean monthly water balance of the Lake and Net ground water change

| water balance components 1993-2012 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| monthly Inflow(mm) | | | | | | | monthly out flow (mm) | | | | |
| | | | | un-gauged subsins | | | | | | | |
| month | PPT | Katar | Meki | north | south | west | outfow | Evap | Abst | change in storage | change d water |
| Jan | 14.32 | 13.84 | 3.88 | 1.17 | 1.23 | 0.66 | 36.82 | 163.14 | 16.72 | -198.55 | -16.98 |
| Feb | 23.15 | 12.57 | 4.25 | 0.94 | 1.59 | 1.02 | 24.80 | 162.32 | 19.64 | -189.37 | -26.14 |
| Mar | 46.15 | 20.50 | 12.28 | 0.88 | 1.76 | 0.87 | 17.03 | 183.23 | 21.58 | -135.89 | 3.51 |
| Apr | 77.45 | 24.98 | 23.61 | 0.93 | 1.73 | 1.26 | 12.72 | 165.98 | 23.58 | -68.39 | 3.93 |
| May | 70.55 | 29.48 | 39.52 | 1.17 | 3.69 | 2.75 | 11.43 | 177.33 | 15.62 | -49.60 | 7.61 |
| Jun | 83.35 | 47.63 | 40.54 | 1.70 | 3.14 | 2.49 | 10.60 | 165.33 | 2.90 | 7.32 | 7.32 |
| Jul | 167.61 | 138.05 | 106.62 | 6.99 | 13.85 | 11.14 | 20.54 | 140.31 | 0.74 | 314.64 | 31.97 |
| Aug | 130.10 | 268.96 | 180.90 | 12.14 | 28.81 | 23.27 | 56.13 | 142.46 | 0.74 | 505.22 | 60.38 |
| Sep | 90.37 | 218.65 | 137.34 | 9.11 | 23.34 | 19.30 | 86.53 | 141.16 | 1.04 | 321.15 | 51.76 |
| Oct | 36.62 | 102.37 | 50.34 | 4.25 | 8.16 | 8.15 | 87.89 | 164.90 | 15.89 | -110.61 | -51.81 |
| Nov | 18.83 | 28.65 | 11.60 | 2.28 | 3.67 | 1.56 | 71.77 | 156.61 | 16.75 | -202.31 | -23.76 |
| Dec | 6.70 | 14.69 | 4.46 | 1.24 | 1.36 | 0.67 | 52.52 | 155.18 | 16.75 | -193.61 | -1.71 |
| yearly (mm) | 765.19 | 920.39 | 615.35 | 42.79 | 92.34 | 73.14 | 488.77 | 1917.95 | 151.9 | 0.00 | 49.49 |
| yearly (MCM) | 336.64 | 404.92 | 270.72 | 18.83 | 40.62 | 32.18 | 215.03 | 843.78 | 66.86 | 0.00 | 21.77 |

PPT, UN-gauged Sub basins, Evap and Abst stands for mean monthly areal rainfall, inflow from un-gauged sub basins, open water evaporation and abstraction from the Lake respectively

From table 4-10 the value of ground water+21.45Mcm this indicating that ground water inflow was significant which could be the possible influence to the lake it has a positive impact to the storage of the reservoir system.

From the table 4-10 if one observes monthly water balance of the lake, the Lake contributes water to the ground water during January to February and October to December and receives water from ground water during months march to September. From the rainfall distribution of the lake watershed, the rainfall of the area is bimodal which has maximum pick during months of July and a minor pick during month of March as described in section 3.3.1. Theses indicate that Lake receives water from ground water immediately after picks rainfall of the area

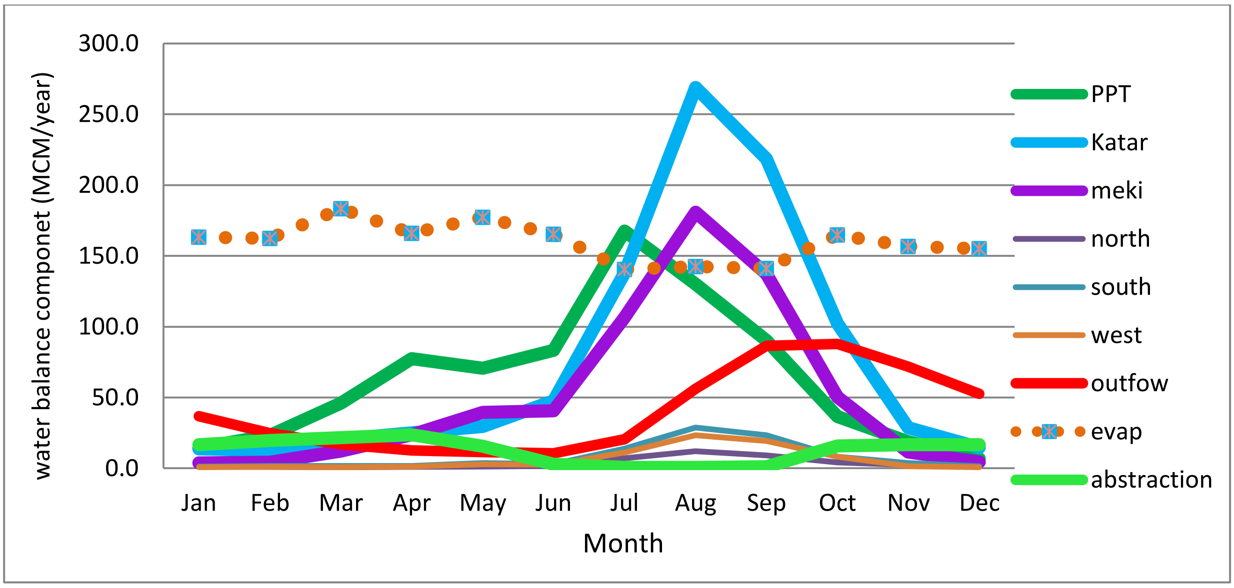



**Figure 4-18 Long term mean annual water balance components of lake in MCM**

## 4.6 Temporary Variation of Hydrological Change in the Water Balance Lake

### 4.6.1 Water balance components

Inflow to the Lake is the sum of lake areal rainfall, runoff from gauged and un-gauged Sub_basins and ground water are the sources of inflow into the lake water balance.

#### 4.6.1.1 *Rainfall*

Rainfall is the main source for the variability in the water balance over space and time, and change in rainfall have very significant effect on hydrology and water resources. Hydrological change on the time in a watershed is influenced by variations in rainfall over daily, seasonal, annual and decade time scale. The volume of Lake is change with the trend of the rainfall. It is 30.49%, covers a total inflow from Lake. The seasonal variability of precipitation is important as it determine the seasonality of the other related hydrological variables such as stream flow, ground water infiltration and likes. As described in section 3.1.1 for most of the station the highest rainfall is recorded between June and September and the lost recorded between October and February.

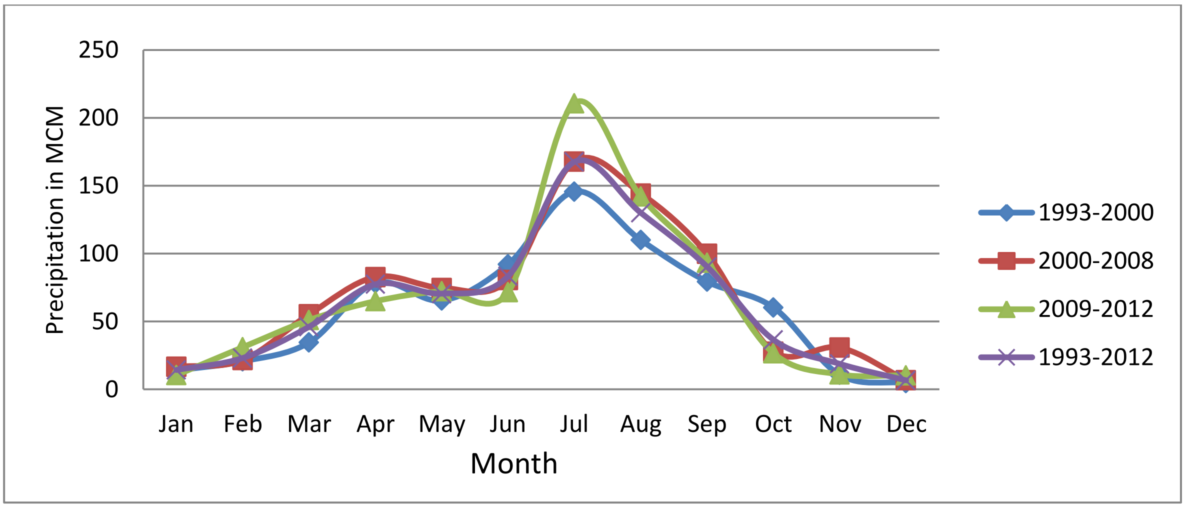



**Figure 4-19 comparison long term annual areal precipitation from the period of 1993-2002 and 2003-2012**

The frequency and amount of precipitation falling in the Lake have changed. A warmer atmosphere can hold more moisture, and globally water vapor increases by 7% for every degree centigrade of warming and the total volume of the precipitation is likely to increase by 1-2 % per degree of warming (Walsh,J and Coauthors , 2014). In the watershed the trend of the temperature is increasing continually which a direct effect of on the precipitation of on the lake. Overall total precipitation has increased by 1.15% comparing to the last ten years from 1993-2002 and the present condition from 2003-2012. Figure 4- 22 shows the assessment of precipitation on the period of 1993-2002 and 2003-2012

##### 4.6.1.1.1 Temperature

The main component of the evaporation is temperature. The trend of temperature is increasing continually which increase the rate of evaporation and then affect the water balance of the lake. In this study the temperature of station is used for analyzing the effects. See Figure 4-23.

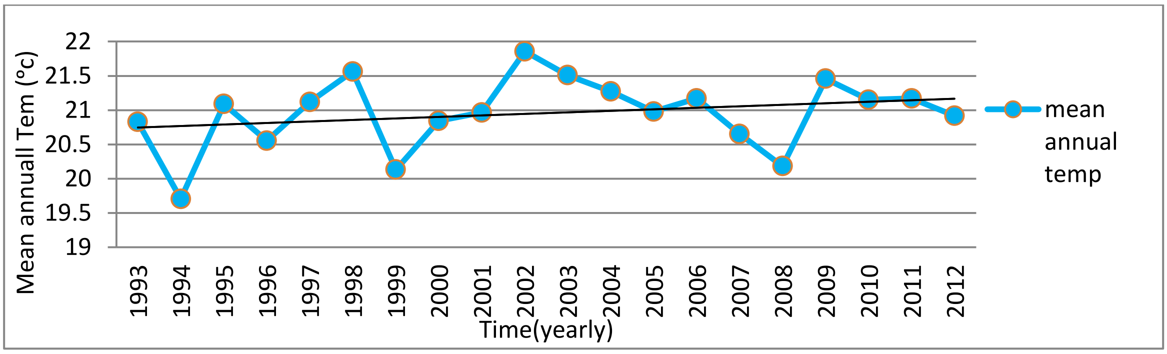



**Figure 4-20 Ziway towns station temperature**

### 4.6.1.2 *Evaporation*

It has a direct relationship between temperature and evaporation. Increasing temperature commonly a consequence in an increasing in potential evaporation mostly this is because the water holding capacity of air is increased. In this study change in evaporation in the study area was calculated by using cropwat methods with the station meteorological data, as described in section 3.3.3.

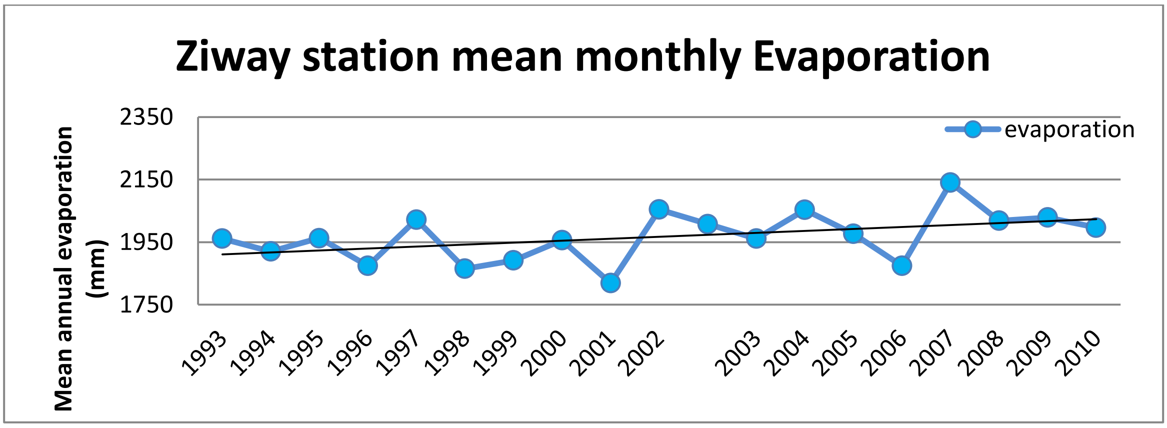



**Figure 4-21 Lake surface evaporation**

### 4.6.1.3 *Annual river inflow and outflow volume of Lake*

It is clear that from the hydrograph of the rivers discharge from Meki, Katarr and Bulbula during the study period it shows declining trend (figure 4-25and figure 4-26). The mean annual discharge the Katarr and Meki Rivers decreased approximately by 19% and 22.09% from the base year 1993. The standard deviation of annual discharge of Katarr and Meki rivers are 134MCM and 124.92MCM respectively. The declining trends of those major rivers may be connected with the expansion of water abstraction from the upper stream of the rivers for irrigation purpose. Total area irrigated land for Katarr sub basins estimate about 1130 ha and annual water abstraction is 13.61 MCM in the year 2012 and 840 ha and 10.2 MCM for Meki rivers see table 3-1 and table 3-2.

The cause of reduction of the flow of those rivers could be governed by other factor such as land use change and global climatic change. The effect of land degradation affects the sustainability of the base flow the river and subsequently affects water balance and results lowering of the level of the lake.

The reduction declining of annual discharge of Katarr River was more observed at recent years. Conversely the base flow of this river never dried up.

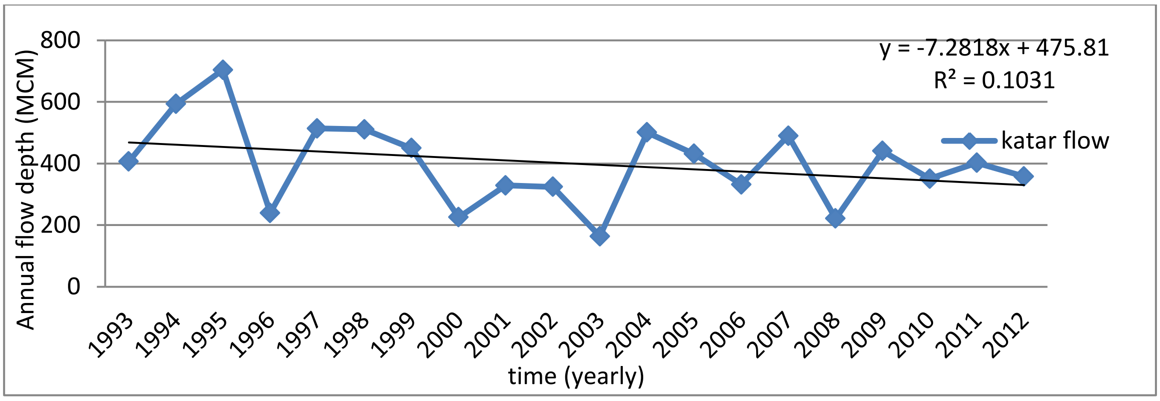



Figure 4-22 Annual Katarr flow 1993-2012

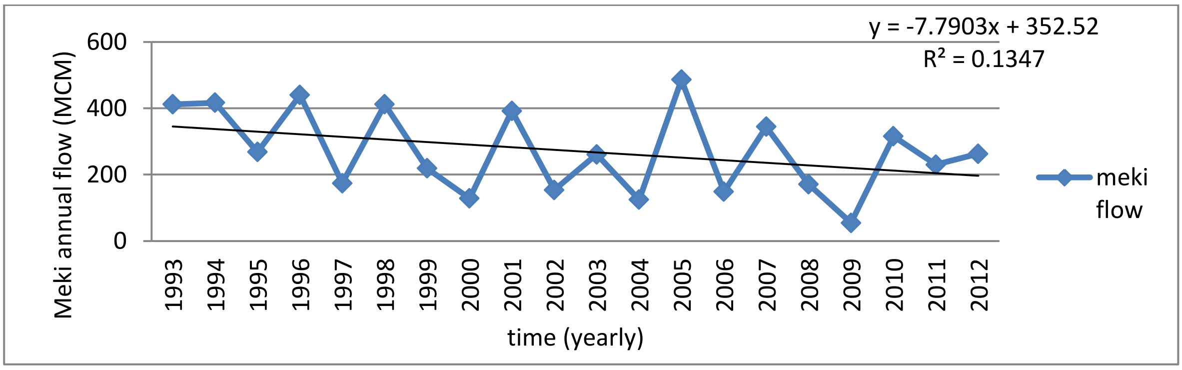



Figure 4-23 Annual flow Meki river 1993-2012

#### 4.6.1.4 *Water Abstraction*

Due to its accessibility, favorable location in relation to Addis Ababa and fresh water quality, Lake has been considered the most important water exploitation area in the rift valley (Halcow, 1992). A total land of 8310 ha is irrigated by using the lake and major perennial rivers around the lakes. See table 3-1 in section 3.7.

Based on the data collected during field visit from OIDA and agricultural development offices currently in Lake is about 5840 ha irrigated by using the lake water. From Meki and Kater rivers about 840 ha and 1130 ha of land cultivated by using water abstracted from the rivers. Table 4-3 shows the abstraction of water from the rivers and lake is increasing in an alarming rate.

Table 4-8 Estimated monthly water abstraction for major irrigation project

| estimated monthly water abstraction for major irrigation projects MCM) | irrigation 2004 (MCM) | irrigation 2008 (MCM) | irrigation 2012 (MCM) |
|---|---|---|---|
| irrigation scheme | | | |
| Meki irrigation | 3.84 | 4.69 | 10.2 |
| Katarr irrigation | 5.36 | 9.83 | 13.61 |
| Ziway irrigation | 27.68 | 44.5 | 75.41 |

*Source: feasibility study for pressurized irrigation (WWDSE, 2008), OIDA and agricultural offices (Tadesse, 2009)*

Using the data from 1993-2012 yearly on monthly basis, the lake watershed water balance computed in three periods of intervals. from figure 4-27, if one observed that the volume of the Lake are decreasing, the rainfall patter of the area doesn't change significantly however evaporation from the lake and abstraction of water from the rivers and lake is increasing in an alarming rate.

From the period of 1993-2000, 2001-2008 and 2009-2012 the annual water balance has an error of -60, -104, and -130mm/year respectively. The source of this inaccuracy can be attributed to the lack of direct measurements of accurate evaporation rate, water abstractions, un-gauged runoff, or else the aspect of assumed net ground change and inaccuracy of data for gauged.

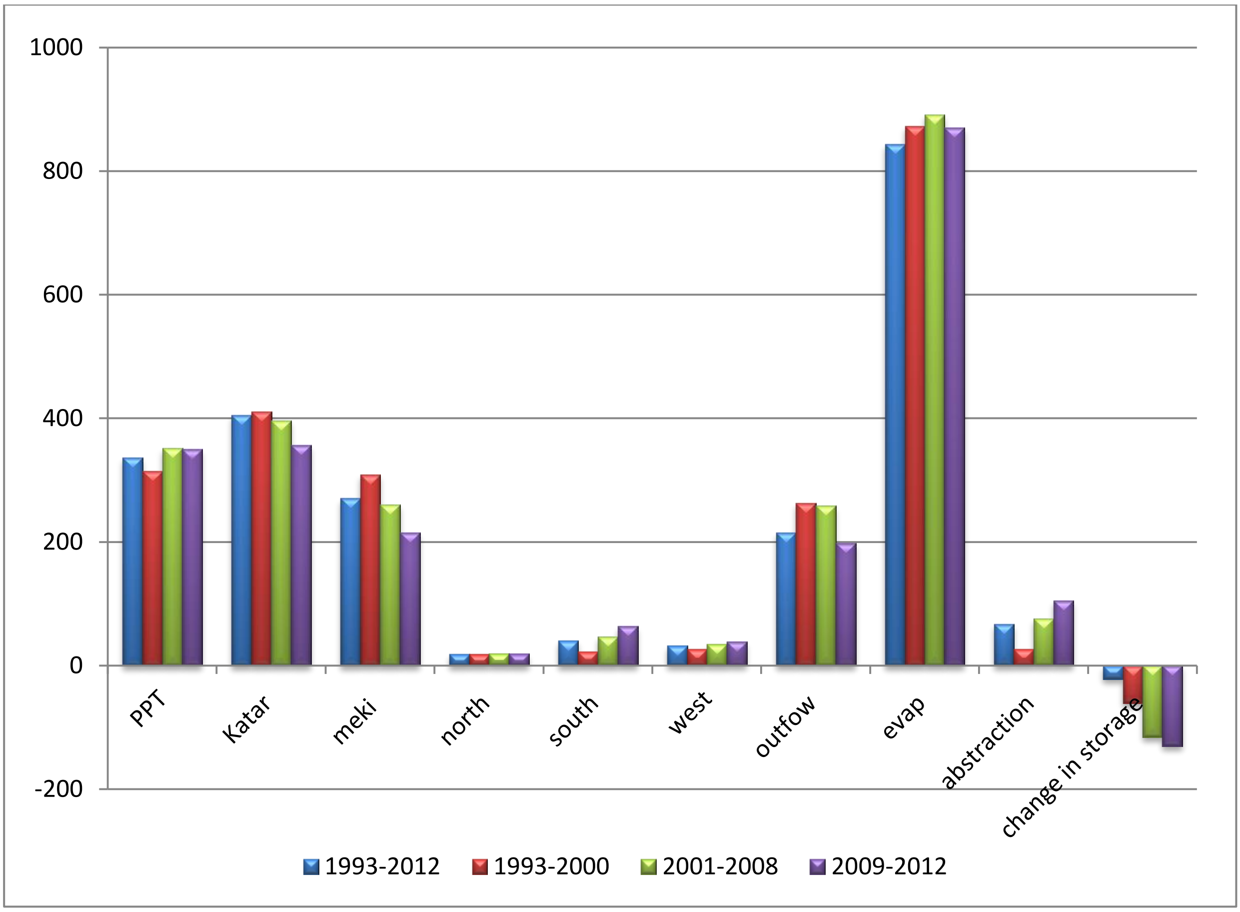



**Figure 4-24 Long term mean annual water balance components of lake without ground water flux**

# 5 Conclusion and recommendation

## 5.1 Conclusion

In this study monthly water balance of lake  watershed was simulated due underlining for un-gauged sub basins. Flow from un-gauged sub basins is estimated by transferring model parameters of gauged sub basins by spatial proximity. Based on the study conducted the following conclusion are drawn.

- A total of 5 sub basins in the lake  watershed besides two rivers gauging station covering 74.84% of the area have continuous river flow data from 1993-2012. The result of simulation with reasonable performance RVE small than +5% or -5% and Ns greater than 0.6 contributing on average of 676.46 MCM/year from 1993 to 2012.
- The totals are of the un-gauged sub basins of 25.16% of the watershed the result of simulation shows contributions in average 91.63 MCM/year inflows to the lake.
- Estimation evaporation from lake based on FAO-CROPWAT 8 model and result of estimation is shows in average 843.81 MCM/ year evaporate from the lake body.
- Estimation water abstraction from the lake and major tributary rivers are by using monthly water usage rate for two cropping pattern. According to this study average annual water abstraction from the lake and major tributaries was estimated 82MCM/year and 23.2 MCM respectively.

## 5.2 Recommendation

Due to the results shown by the water balance of Lake , the following recommendations forwarded.

- The study aims to estimate the runoff contribution from gauged and un-gauged sub-basins based on HBV model. HBV model calibrated using observed flow data at gauging station. In order to improve the model performance, the weather stations should be improved both in quality and quantity. Hence, it is highly recommended to establish a good network of both hydrometric and metrological stations.

- More detailed water resources assessment should require, including sustainable water abstraction from the lake and their major tributaries. Particularly, Special emphasis is required on the water abstraction for different agricultural, floricultural and horticulture production by using water abstract from the lake and major tributaries and detail crop-water requirements study has to be made in irrigation fields to protect the over abstraction of the resources

- There is need for explorative ground water resource studies to obtain solid facts on ground water potential in the lake and surrounding of the lake in order to shift some of the irrigation schemes to this resources
- Mitigation should be taken to reduce loss of water due to evaporation in lake surface

## *Reference*


Amirew, D. (2006). *Modelling of hydrology and Soil Erosion of upper Awash River Basin PhD Thesis, University of Bonn 233pp.*

Ayenew, T. (2007). some Improper water Resourecs Utilization Practice and Enviromental Problems in Ethiopia Rift valley. *Africa Water Jounal 1*, 83-108.

Bergstrom, S. (1991). *THE HBV STORY IN SWEDEN Swedish Meteorological and hydrological Instiyute Norrkoping* . Sweden.

Booij, M. a. (2007). *Regionalisation for uncertainty reducation in flows in un-gauged basins In: Quantification and reducation of predictive uncertainty for sustainble water resources management:procedding of symposium HS@))$ at IUGG2007, Perugia, 7-13 July 2007/ ed.*

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology* . New York: McGraw-Hill.

Dagnachew Legesse, Z. W. (2005). A Review of the Current Status and an Outline of a Future Management plan for Lakes Abijata and Ziway, Draft final report, Addis Ababa, The Federal Government of Ethiopia, Oromia Environmental Protection Authority.

Degafu. (1987). *Some Aspects of meteorological Drought in Ethiopia. In Drought and Hunger in Africa, Glantz MH (ed.* Cambridge: University Pres.

Dingman, S. (2002). *Physical Hydrology Upper Saddle River (2nd ed.), Prentice Hall Inc..,.* USA.

Dribsa, A. (2006). *Groundwater-surface water interaction and analysis of recent changes in hydrologic environment Lake Ziway catchment. Unpublished MSc Thesis,.* Addis Ababa, Ethiopia. .

Garbrecht,J and L.W.Martz . (2000). Digital Elevation Model Issues in water resources modelling . *Hydrology Volume 192(Issues 1-4)*, 81-103.

Halcow. (1992). *Reconnaissance master plan for the development of the natural resources of the Rift Valley Lakes Basin, vol.3. Ethiopian Valleys Development Studies AuthorityAddis Ababa. .*

Halcrow. (1989). *Master Plan for the Development of Surface Water Resources in the Awash Basin, vol. 6.* Addis Ababa, Ethiopia: MoWR.

Helco, J. H. (2007). *Land and Water Assessment in the Ethiopia Central Rift Valley,Alterra Report 1587.* Wageningen: The Netherland.

IHMS. (2012). *Integrated Hydrological Modelling System featuring HBV Version 6.3.*

Legesse, D. (2004). *Analysis of hydrological response of a tropical terminal lake, lake Abiyata(Main Ethiopian Rift valley) to changes in climate and human activities. hydrological process.18:487-504.*

Liden and Harlin. (2000). Analysis of conceptual rainfall-runoff modelling performance in different climates. *Journal of Hydrlogy,238,* 231-247.

Maidment. (1993). *Hand book of Hydrology, McGraw-Hill.*

Maidment, D. (1993). *Hand book of hydrology.* New York: McGraw Hall.

Makin, M. K. (1976). *prospects for irrigation development around Lake Ziway, Ethiopia.* land resourecs division , ministry of overseas.

Makin, M. K. (1976). Prospects for irrigation development around Lake Ziway, Ethiopia. Land Res. Study. *Division, Ministry of Overseas Development, 26. Tolworth, UK*, 270.

Merz, R and G. Bloschl. (2004). regionalization of catchemnt model parametrs. *journal of hydrology 287(1-4):95-123.*

Moti, J. (2002). *Interlocked Markets and Intensity of Input use in Vegetable Production. A Case around Lake Ziway, Oromiya Region, Ethiopia. MSc Thesis presented to School of Graduate Studies of Wageningen University.*

OEPO. ( 2005). A Review of the Current Status and an Outline of a Future Management Plan for Lakes Abiyata and Ziway. *Draft Final Report. Sponsored by UNDP-CCF2 Program, Addis Ababa, Ethiopia*, 104pp.

OEPO. (2005). A Review of the Current Status and an Outline of a Future Management Plan for Lakes Abiyata and Ziway. *Draft Final Report. Sponsored by UNDP-CCF2 Program, Addis Ababa, Ethiopia*, 104pp.

OIDA, J. &. (2001). *The study for meki irrigation and rural development project.*

Rientjes, T. (2007). Modelling in Hydrology department of water resources,ITC, Enschede.

Rientjes, T.H. (2007). Modelling in Hydrology .

Selshi Bekele Awulachew, Aster Denekew Yilma, Makonnen Lousged W.Loiskandl Tena alamarew and Mekonnen ayana. (2007). *water Resources and Irrigation Development in Ethiopia.* IWMI, working paper 123.

Shiklomanov, I. (1974). *Hydrological Cycle vol ll-World water balance* . UNESCO.

Sivapalan, M. T. (2003). "IAHS Decade on predictions in Un giged Basins (PUB), 2003-2012: Shaping an excuting for the hydrological sciences". *Hydrological Science-Journal-desscience Hydrologiques* , 48(6).

SMHI. (2006). *Intergrated Hydrological Modelling System Manual Version 5.10.* Seweden.

SMHI. (2006). manual of HBV model.

subramanya. (2008). *hydrology books* .

Tadesse, T. (2009). *water resource utilization and its related effects lake Abiyata and the surrounding* .

Tenalem Ayenew. (2004). *Enviromental implications of changes in the levels of lake inthe Ethiopian rift since 1970.* regional rural change 4:192-204.

Tesfaye Chernet, W. a. (1982). *The Hydrogeology of the Lakes Region, Ethiopia (Lakes Ziway, Langano, Abiyata, Shalla, Awassa)Memoir no. 7, the Provisional*

*Military Government of Socialist Ethiopi.* Addis Ababa.: Ministry of Mines and Energy, Ethiopian Institute of Geological Surveys.

UNESCO. (1974). *Methods of Water Balance computations an international guid for research and practice.* Paris: UNESCO Press.

UNESCO. (1974). *Methods of Water Balance Computations. An International Guid For research and practice.* Paris: UNESCO Press.

UNESCO. (2008). *The United Nations World Development Report, World water assessment program.*

USUG. (2012). *National water use* . united state: water scince gschool .

Ven Te Chaw, David R. Maidment, Larry W.Mays. (n.d.). *Applied Hydrology.* McGRAW-HILL INTRNATIONAL EDITIONS civil engineering series.

Walsh,J and Coauthors . (2014). *climate change impacts in the united states ;The thrid national climate assessment* . Michigan state: University of Michigan .

Wondifraw, A. M. (2008). *Assessment of lake ziway water balance* .

WWDSE. (2008). *Ziway Irrigation Project Final Feasibility Report AnnexA.*

www.ethiovisit.com. (n.d.). *major rivers basins of ethiopia.*

Zeray, L. (2006). *climate changeimpact on ziway lake watershed water availability. MSc thesis presented to the universtity of applied sciences, cologne institue for techonology innthe tropics (ITT).* Germany.

## Appendix 1.HBV model parameters description

| Soil moisture routine parameters: | |
|---|---|
| fc | Field capacity (mm). / 200 / |
| lp | Limit for potential evaporation. Must be 1.0 or less. / 0.9 / |
| beta | Exponent in formula for drainage from soil. / 2.0 / |
| etf | Temperature factor for evaporation. Potential evaporation will be adjusted according to the formula: $E = E0 (1 + etf \cdot \partial t)$ where $\partial t$ is deviation of temperature from normal value. This parameter can only be used if normal value of temperature (ctemp locmean) is available. Therefore this parameter must be zero (or <0) at the first run after which normal values can be computed. At such a run all subbasins must have presentation status = pres (see description of BASIN.PAR). This can be achieved by setting etf=-1 This value will temporarily set presentation status= pres for all subbasins and no correction of evaporation will occur. When the parameter is used for later runs a value of 0.1 is recommended. |
| cflux | Maximum capillary flow from upper response box to soil moisture zone (mm/day). / 1.0 / |
| ecorr | General correction factor for potential evaporation. / 1.0 /.This parameter does not affect evaporation if the Thornthwaite type method is chosen by use of the parameter athorn. |
| cevpfo | Correction factor for potential evaporation in forest zones. / 1.15 - if hbv96 is off the default value is / 1.0 / |
| ecalt | Elevation correction factor for evaporation. Evaporation values will be multiplied by $1 - h \cdot ecalt$, where h is altitude difference (hundreds of metres) between current zone elevation and evaporation station elevation (or weighted mean of several stations). / 0.1 / |
| athorn | If this parameter is >0 a simplified version of Thornthwaites formula will be used to calculate the potential evaporation: $Epot = athorn \cdot TEMP$, where TEMP is the current air temperature. |
| stf | Switch used to turn on a set of seasonal factors by which the parameter athorn will be multiplied. The parameter may have the value 0, 1 or 2. If zero no factors will be used. If value is 1 the following set of factors will be used (one value for each month): 0.7 0.7 0.8 1.0 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.7. If stf=2 the following set is used: 0.6 1.9 2.4 1.8 1.4 1.3 1.0 .0.9 0.6 0.4 0.2 0.3. These values were developed for Scandinavian conditions and can not be assumed to be valid in general |
| soilstep | If this parameter =1 all the soil zones will be considered as one zone and only one soil computation will be performed at each timestep to save computation time. |

| Response routine parameters: | |
|---|---|
| | |
| Ko | k0 Top recession coefficient for upper response box.(day-1) |
| Uzlo | Lower limit for k0 recession (mm). |
| K1 | Second recession coefficient for upper response box. (day-1) |
| Uzl1 | Lower limit for k1 recession (mm). |
| k2 | Third recession coefficient for upper response box. (day-1) |
| uzl2 | Lower limit for k2 recession (mm). |
| k3 | Bottom recession coefficient for upper response box. (day-1) |
| k4 | Recession coefficient for lower response box. (day-1) |
| perc | Percolation capacity (mm/day) from upper to lower response box |
| khq<br><br>hq | Recession coefficient for the upper box when water discharge equals hq. When this parameter is used (khq>0) the parameters k0-k3 will not be used. In this case outflow is calculated according to the formula Q =k · UZ(alfa+1) The factor k is calculated by the program so that the recession coefficient for hq will be equal to khq (unit: day-1). /0.17/<br>See khq (unit: mm/day) /3/ |
| alfa | See khq /1/ |
| recstep | Number of internal computation steps in this routine during a day. If recstep > 998 an appropriate number of steps will be computed by the program depending on the outflow from the response box. / 999 /. Default value also set to 999 if the parameter khq > 0, otherwise default value is 1. |
| resparea | If this parameter >0 the parameter perc (percolation capacity) is reduced by (sm/fc)^beta. /0/ |

| | Transformation routine parameter: |
|---|---|
| maxbas | Number of days in the transformation routine. Maxbas is not restricted to integer values. The model program will automatically assure that the time base maxbas will not be shorter than the chosen timestep. Maxbas = one timestep means that no transformation of runoff is made within a sub-catchment. Old version – not recommended för new applications. |
| maxbaz | Number of days in the transformation routine. Maxbaz = 0 means that no transformation of runoff is made within a sub-catchment Maxbaz is not restricted to integer values. Replaces maxbas for new applications. |
| | **Lake parameters:** |
| cevpl | Factor multiplied by potential evaporation to give evaporation from lakes. / 1.1 - if hbv96 is off default value is 1 / |
| icef | Last day with ice cover on lakes (mmdd where mm is month and dd day). |
| lakedays | If icef is zero the program will use an estimated water temperature to decide whether there is an ice cover or not This estimated water temperature is depending on the air temperature during the last time period given by the parameter lakedays (number of days in the period). This temperature is also used when lake evaporation is calculated using the simplified version of Thornthwaites formula / 30 / |
| | **Lake parameters:** |
| elag | When calculating lake evaporation using standard evaporation values the potential evaporation from a day elag days before current day will be used. / 30 / |
| | **Criteria routine parameter:** |
| critstep | Number of time steps for which the results are accumulated before calculation |

## Appendix 2. HBV model parameters and their starting values as suggested by SMHI Manual

| Parameter | Starting value | Approx interval | Comments |
|---|---|---|---|
| Pcorr 1.0 | 1.0 | | Factor for precipitation. Used when correcting non-homogenous series. |
| Pcalt | 0.1 | | Factor for precipitation changing with altitude |
| Pcaltl | 800 | | Highest level when pcalt is used. Locked to the highest forested level. |
| Pcaltup | 0.0 | | Factor for precipitation falling in areas above pcaltl. |
| Pcaltgl | 0.1 | | Factor for precipitation in areas with glaciers situated above pcaltl. |
| Tcalt | 0.6 | | Decrease of temperature with altitude taken per 100 meter. |
| Rfcf | 1.0 | 0.9 – 1.3 | Factor for precipitation as rain. Multiplied by pcorr. The quota rfcf/sfcf = max 1.5. |
| Sfcf | 1.0 | 0.8 – 1.4 | Factor for precipitation as snow. Multiplied by pcorr. |
| Fosfcf | 0.8 | | Multiplied by sfcf for forested areas. |
| Cfmax | 3.0 | 2 – 4.5 | Factor for snowmelt [mm/°C, day]. Governs the rate of snowmelt. |
| Focfmax | 0.6 | | Multiplied by cfmax for forested areas Governs the rate of snowmelt in forested areas. |
| Tt | 0.0 | -2° - 2° | Threshold temperature for precipitation. Decides whether it falls as snow or rain [°C]. |
| Dttm | -0.5 | -2° - 2° | Value added to tt to reach threshold temperature for snowmelt [°C]. |
| Tti | 0 – 0.5 | 0° – 2.5° | Threshold temperature interval. Governs precipitation as sleet. Tt is in the middle |

| Parameter | Starting value | Approx interval | Comments |
|---|---|---|---|
| | | | of the interval. |
| Gmelt | 4.0 | | Factor for melting of glaciers [mm/°C, day]. |
| Cfr. | 0.05 | | Factor for refreezing in the snowpack |
| Whc | 0.1 | | Waterholding capacity for the snowpack. |
| Sfdistfo | Use a value for the region | | Snow distribution in forested areas. |
| Sfdistfi | Use a value for the region | | Same as sfdistfo, but for areas with no forest. |
| Sclass | 3 | | Number of snow classes. |
| Fc | Use a value for the region | 100 - 1500 | Maximum soil moister storage [mm]. |
| Lp | 1.0 | <=1 | Limit for potential evaporation. |
| Beta | 1.0 | 1 - 4 | Exponent in the equation for discharge from the zone of soil water. |
| Cflux | 0.5 | 0 - 2 | Capillary flow from the upper response box to the zone of soil water. |
| Cevpfo | 1.15 | | Factor for potential evaporation in forested areas. |
| Athorn | 0.25 | 0.2 – 0.3 | If >0 a simplified version of Thornthwaites equation is used. Unit [mm/day °C]. |
| Stf | 2 | | Describes seasonal variations in respect of athorn. |
| K4 | 0.01 | 0.001 – 0.1 | Recession coefficient for the lower response box. |
| Perc | 0.5 | 0.01 - 6 | Percolation from the upper to the lower response box [mm/day]. |
| Khq | 0.09 | 0.005 – 0.2 | Recession coefficient for the upper response box when the discharge is HQ. |
| Hq | Should be calculated | | May be calculated as (MQ·MHQ)1/2 ·86.4/(area in km2) or MHQ/2·86.4/(area in km2). Unit [mm]. Not to be calibrated. |
| Alfa | 0.9 | 0.5 – 1.1 | Used in the equation Q = k·UZ(alfa+1). |
| Maxbaz | 1 | 1 - 5 | Number of days (doesn't have to be an integer) in the transformation routine. |
| Maxbaz | 1 | 1 - 5 | Number of days (doesn't have to be an integer) in the transformation routine. |
| Lakedays | 30 | | The deeper the lake, the higher value. |
| Ttice | 0.0 | | Above this water temperature there is no ice covering the lakes. |
| Recstep | 999 | | Number of steps/days is automatically checked. |

## Appendix 3. Monthly Lake Water balance

| Date | level | area km2 | observed volume mcm | precipitation mcm | Meki inflow mcm | Katarr inflow mcm | total un-gauged flow mcm | outflow MCM | *abstraction mcm* | *evaporation mcm* | *Gin and G out mcm* | *change in storage in mcm* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan-93 | 1.3 | 447.1 | 1393.9 | 14.3 | 1.1 | 5.4 | 1.5 | 22.7 | *4.6* | *68.5* | *-23.8* | *-65.5* |
| Feb-93 | 1.2 | 443.4 | 1354.3 | 12.6 | 1.0 | 4.9 | 4.1 | 17.1 | *5.4* | *68.2* | *-34.9* | *-49.9* |
| Mar-93 | 1.1 | 439.2 | 1285.7 | 7.8 | 1.8 | 5.0 | 1.5 | 9.0 | *5.9* | *76.9* | *1.5* | *-75.8* |
| Apr-93 | 1.0 | 437.1 | 1229.1 | 42.1 | 33.3 | 4.7 | 1.7 | 5.1 | *6.5* | *73.0* | *1.7* | *-2.9* |
| May-93 | 1.0 | 438.7 | 1274.7 | 50.3 | 37.5 | 9.8 | 4.2 | 13.0 | *4.3* | *78.0* | *4.2* | *6.5* |
| Jun-93 | 1.1 | 440.6 | 1313.1 | 35.9 | 23.3 | 34.7 | 6.7 | 19.2 | *0.7* | *72.7* | *6.7* | *8.0* |
| Jul-93 | 1.2 | 444.8 | 1370.5 | 86.7 | 72.9 | 47.6 | 20.3 | 27.7 | *0.1* | *61.7* | *20.3* | *138.0* |
| Aug-93 | 1.6 | 472.4 | 1535.9 | 41.4 | 149.8 | 107.4 | 27.7 | 56.9 | *0.1* | *62.7* | *27.7* | *206.6* |
| Sep-93 | 1.8 | 505.1 | 1628.1 | 29.2 | 65.0 | 79.7 | 16.2 | 72.4 | *0.2* | *62.1* | *16.2* | *55.4* |
| Oct-93 | 1.8 | 503.3 | 1624.1 | 23.9 | 24.3 | 41.0 | 5.3 | 66.2 | *4.3* | *72.5* | *-29.2* | *-48.6* |
| Nov-93 | 1.6 | 478.8 | 1558.3 | 0.1 | 1.1 | 11.6 | 3.4 | 48.3 | *4.6* | *68.9* | *-3.5* | *-105.6* |
| Dec-93 | 1.5 | 458.7 | 1475.1 | 0.2 | 1.1 | 6.2 | 1.3 | 34.3 | *4.6* | *68.3* | *-1.5* | *-98.4* |
| Jan-94 | 1.3 | 447.0 | 1392.9 | 0.0 | 1.2 | 5.9 | 1.3 | 21.3 | *4.6* | *68.5* | *-1.3* | *-85.9* |
| Feb-94 | 1.1 | 441.2 | 1322.7 | 0.1 | 1.0 | 5.2 | 1.3 | 12.7 | *5.4* | *68.2* | *-1.4* | *-78.6* |
| Mar-94 | 1.0 | 437.2 | 1232.0 | 11.9 | 4.1 | 5.3 | 1.3 | 8.9 | *5.9* | *76.9* | *1.3* | *-69.1* |
| Apr-94 | 0.8 | 435.6 | 1172.7 | 13.9 | 5.2 | 4.9 | 1.2 | 3.1 | *6.5* | *73.0* | *1.2* | *-57.4* |
| May-94 | 0.7 | 434.5 | 1118.0 | 22.7 | 49.9 | 4.8 | 1.1 | 0.1 | *4.3* | *78.0* | *1.1* | *-3.9* |
| Jun-94 | 0.7 | 434.4 | 1111.8 | 69.4 | 21.6 | 11.0 | 3.0 | 0.1 | *0.7* | *72.7* | *3.0* | *31.3* |
| Jul-94 | 0.8 | 435.4 | 1164.1 | 65.8 | 75.5 | 87.5 | 17.9 | 0.1 | *0.1* | *61.7* | *17.9* | *184.8* |
| Aug-94 | 1.3 | 448.8 | 1409.1 | 40.4 | 100.6 | 132.3 | 26.8 | 10.6 | *0.1* | *62.7* | *26.8* | *226.8* |
| Sep-94 | 1.7 | 488.6 | 1587.7 | 25.4 | 128.2 | 107.5 | 19.1 | 38.8 | *0.2* | *62.1* | *19.1* | *179.0* |
| Oct-94 | 1.8 | 497.3 | 1610.0 | 0.4 | 21.8 | 26.3 | 7.0 | 48.6 | *4.3* | *72.5* | *-7.3* | *-70.0* |
| Nov-94 | 1.5 | 458.2 | 1472.3 | 2.0 | 6.6 | 5.7 | 1.3 | 36.3 | *4.6* | *68.9* | *-3.3* | *-94.1* |
| Dec-94 | 1.3 | 449.5 | 1414.8 | 0.0 | 1.1 | 5.7 | 1.3 | 27.4 | *4.6* | *68.3* | *-1.4* | *-92.1* |
| Jan-95 | 1.2 | 443.3 | 1352.8 | 0.0 | 1.1 | 5.4 | 1.3 | 14.0 | *4.6* | *68.5* | *-1.3* | *-79.2* |
| Feb-95 | 1.1 | 439.6 | 1294.4 | 11.6 | 2.3 | 4.8 | 1.2 | 5.9 | *5.4* | *68.2* | *-12.8* | *-59.5* |
| Mar-95 | 1.0 | 437.1 | 1229.6 | 28.9 | 6.2 | 12.5 | 1.3 | 4.0 | *5.9* | *76.9* | *1.3* | *-38.0* |
| Apr-95 | 0.9 | 436.3 | 1202.3 | 50.4 | 50.8 | 15.9 | 1.4 | 1.2 | *6.5* | *73.0* | *1.9* | *38.3* |
| May-95 | 1.0 | 437.9 | 1254.5 | 10.7 | 46.2 | 21.8 | 3.3 | 4.8 | *4.3* | *78.0* | *3.5* | *-4.8* |
| Jun-95 | 0.9 | 436.7 | 1216.2 | 21.0 | 24.7 | 11.6 | 1.5 | 2.6 | *0.7* | *72.7* | *1.4* | *-17.4* |
| Jul-95 | 0.9 | 436.5 | 1210.4 | 36.0 | 45.2 | 39.3 | 2.7 | 2.9 | *0.1* | *61.7* | *3.0* | *58.8* |
| Aug-95 | 1.2 | 443.0 | 1348.0 | 32.7 | 45.2 | 81.5 | 3.0 | 10.2 | *0.1* | *62.7* | *2.9* | *89.4* |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sep-95** | **1.5** | **458.5** | **1473.7** | **22.6** | **39.5** | **117.5** | **5.4** | **24.2** | ***0.2*** | ***62.1*** | ***5.4*** | ***98.5*** |
| **Oct-95** | **1.4** | **453.8** | **1446.0** | **1.8** | **3.8** | **27.3** | **1.7** | **30.8** | ***4.3*** | ***72.5*** | ***-3.3*** | ***-73.3*** |
| **Nov-95** | **1.2** | **443.0** | **1348.5** | **1.9** | **1.0** | **6.8** | **1.3** | **20.7** | ***4.6*** | ***68.9*** | ***-3.2*** | ***-83.1*** |
| **Dec-95** | **1.1** | **439.0** | **1281.9** | **4.4** | **2.2** | **6.5** | **1.3** | **8.4** | ***4.6*** | ***68.3*** | ***-5.7*** | ***-66.9*** |
| **Jan-96** | **1.0** | **437.3** | **1236.8** | **10.4** | **9.4** | **6.2** | **1.3** | **4.9** | ***4.6*** | ***68.5*** | ***-11.7*** | ***-50.7*** |
| **Feb-96** | **0.8** | **435.6** | **1169.8** | **4.1** | **1.0** | **5.5** | **1.2** | **1.6** | ***5.4*** | ***68.2*** | ***-5.1*** | ***-63.5*** |
| **Mar-96** | **0.7** | **434.5** | **1117.0** | **15.9** | **14.9** | **5.6** | **1.1** | **0.8** | ***5.9*** | ***76.9*** | ***1.1*** | ***-46.1*** |
| **Apr-96** | **0.8** | **434.8** | **1135.1** | **32.0** | **14.7** | **5.5** | **1.0** | **0.8** | ***6.5*** | ***73.0*** | ***1.0*** | ***-27.2*** |
| **May-96** | **0.9** | **436.2** | **1198.9** | **51.8** | **38.3** | **12.1** | **1.5** | **2.3** | ***4.3*** | ***78.0*** | ***1.6*** | ***19.2*** |
| **Jun-96** | **1.1** | **439.2** | **1284.8** | **56.7** | **83.2** | **54.7** | **3.3** | **7.0** | ***0.7*** | ***72.7*** | ***4.5*** | ***118.6*** |
| **Jul-96** | **1.4** | **450.3** | **1420.9** | **50.7** | **82.6** | **86.1** | **10.4** | **19.3** | ***0.1*** | ***61.7*** | ***13.7*** | ***152.0*** |
| **Aug-96** | **1.8** | **513.1** | **1644.7** | **49.1** | **118.3** | **111.2** | **17.9** | **55.9** | ***0.1*** | ***62.7*** | ***17.9*** | ***177.9*** |
| **Sep-96** | **2.2** | **645.0** | **1806.1** | **35.1** | **64.6** | **105.0** | **24.7** | **92.8** | ***0.2*** | ***62.1*** | ***21.9*** | ***71.5*** |
| **Oct-96** | **2.2** | **611.1** | **1776.7** | **0.3** | **10.6** | **36.0** | **5.1** | **77.1** | ***4.3*** | ***72.5*** | ***-4.0*** | ***-103.4*** |
| **Nov-96** | **1.9** | **522.6** | **1662.8** | **6.5** | **1.5** | **6.6** | **1.6** | **48.5** | ***4.6*** | ***68.9*** | ***-8.0*** | ***-105.9*** |
| **Dec-96** | **1.7** | **483.3** | **1572.3** | **0.0** | **1.1** | **6.4** | **1.3** | **33.5** | ***4.6*** | ***68.3*** | ***-1.3*** | ***-97.5*** |
| **Jan-97** | **1.5** | **464.1** | **1501.7** | **4.9** | **2.3** | **6.1** | **1.3** | **23.0** | ***4.6*** | ***68.5*** | ***-6.1*** | ***-81.6*** |
| **Feb-97** | **1.4** | **453.0** | **1440.8** | **6.6** | **1.1** | **5.4** | **1.2** | **17.1** | ***5.4*** | ***68.2*** | ***-7.6*** | ***-76.5*** |
| **Mar-97** | **1.2** | **444.6** | **1368.1** | **11.6** | **1.7** | **5.5** | **1.1** | **10.1** | ***5.9*** | ***76.9*** | ***1.1*** | ***-73.1*** |
| **Apr-97** | **1.2** | **444.4** | **1365.3** | **78.8** | **11.6** | **10.9** | **1.6** | **18.8** | ***6.5*** | ***73.0*** | ***1.7*** | ***4.8*** |
| **May-97** | **1.2** | **443.8** | **1358.6** | **12.8** | **5.9** | **8.9** | **2.7** | **15.4** | ***4.3*** | ***78.0*** | ***2.7*** | ***-67.3*** |
| **Jun-97** | **1.1** | **440.1** | **1303.0** | **54.9** | **14.4** | **13.7** | **2.4** | **8.2** | ***0.7*** | ***72.7*** | ***2.7*** | ***4.0*** |
| **Jul-97** | **1.2** | **443.1** | **1349.5** | **71.3** | **32.3** | **52.3** | **8.5** | **14.4** | ***0.1*** | ***61.7*** | ***12.4*** | ***92.0*** |
| **Aug-97** | **1.4** | **450.7** | **1423.8** | **26.1** | **46.9** | **55.6** | **17.5** | **24.1** | ***0.1*** | ***62.7*** | ***17.3*** | ***58.9*** |
| **Sep-97** | **1.4** | **454.9** | **1453.1** | **9.8** | **28.3** | **31.4** | **7.2** | **26.1** | ***0.2*** | ***62.1*** | ***3.9*** | ***-15.1*** |
| **Oct-97** | **1.3** | **449.4** | **1413.8** | **29.8** | **18.1** | **15.5** | **2.8** | **22.7** | ***4.3*** | ***72.5*** | ***-32.1*** | ***-34.0*** |
| **Nov-97** | **1.3** | **447.7** | **1399.1** | **2.0** | **9.7** | **9.2** | **2.5** | **19.2** | ***4.6*** | ***68.9*** | ***-4.4*** | ***-69.3*** |
| **Dec-97** | **1.2** | **442.3** | **1338.5** | **1.9** | **1.6** | **6.7** | **1.3** | **12.6** | ***4.6*** | ***68.3*** | ***-3.3*** | ***-73.9*** |
| **Jan-98** | **1.1** | **439.0** | **1281.9** | **8.1** | **2.2** | **6.4** | **1.3** | **7.2** | ***4.6*** | ***68.5*** | ***-9.5*** | ***-62.2*** |
| **Feb-98** | **1.0** | **437.2** | **1234.9** | **17.4** | **3.2** | **5.8** | **1.3** | **3.8** | ***5.4*** | ***68.2*** | ***-18.5*** | ***-49.9*** |
| **Mar-98** | **0.9** | **436.7** | **1217.6** | **17.7** | **28.1** | **5.9** | **1.1** | **3.2** | ***5.9*** | ***76.9*** | ***1.2*** | ***-33.2*** |
| **Apr-98** | **0.9** | **436.0** | **1188.4** | **23.0** | **6.4** | **5.5** | **1.1** | **0.9** | ***6.5*** | ***73.0*** | ***1.0*** | ***-44.5*** |
| **May-98** | **0.8** | **435.6** | **1169.3** | **18.7** | **25.8** | **5.9** | **1.0** | **1.2** | ***4.3*** | ***78.0*** | ***1.0*** | ***-32.0*** |
| **Jun-98** | **0.8** | **435.2** | **1153.1** | **26.4** | **10.7** | **8.3** | **1.1** | **1.5** | ***0.7*** | ***72.7*** | ***1.1*** | ***-28.3*** |
| **Jul-98** | **0.9** | **436.3** | **1201.8** | **66.0** | **44.1** | **72.7** | **3.4** | **2.0** | ***0.1*** | ***61.7*** | ***4.2*** | ***123.2*** |
| **Aug-98** | **1.4** | **456.6** | **1463.4** | **80.4** | **120.3** | **127.8** | **28.7** | **24.5** | ***0.1*** | ***62.7*** | ***34.8*** | ***276.0*** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sep-98** | **2.0** | **544.2** | **1697.9** | **42.7** | **114.9** | **104.0** | **28.7** | **63.3** | ***0.2*** | ***62.1*** | ***25.8*** | ***161.7*** |
| **Oct-98** | **2.1** | **598.4** | **1764.3** | **38.9** | **48.1** | **124.5** | **28.1** | **85.4** | ***4.3*** | ***72.5*** | ***-69.7*** | ***80.0*** |
| **Nov-98** | **2.0** | **567.6** | **1729.6** | **0.6** | **4.9** | **16.9** | **9.1** | **72.0** | ***4.6*** | ***68.9*** | ***-3.6*** | ***-120.1*** |
| **Dec-98** | **1.8** | **499.9** | **1616.2** | **0.0** | **3.0** | **6.6** | **1.7** | **55.5** | ***4.6*** | ***68.3*** | ***-1.3*** | ***-117.4*** |
| **Jan-99** | **1.6** | **468.2** | **1519.8** | **1.7** | **1.5** | **6.3** | **1.3** | **39.5** | ***4.6*** | ***68.5*** | ***-3.1*** | ***-101.6*** |
| **Feb-99** | **1.4** | **451.2** | **1428.0** | **0.5** | **1.0** | **5.6** | **1.3** | **25.5** | ***5.4*** | ***68.2*** | ***-1.8*** | ***-90.7*** |
| **Mar-99** | **1.2** | **443.9** | **1359.5** | **22.5** | **2.7** | **5.8** | **1.3** | **20.8** | ***5.9*** | ***76.9*** | ***1.1*** | ***-71.5*** |
| **Apr-99** | **1.1** | **439.7** | **1296.3** | **2.8** | **1.1** | **5.5** | **1.1** | **11.4** | ***6.5*** | ***73.0*** | ***1.0*** | ***-80.5*** |
| **May-99** | **1.0** | **437.1** | **1231.5** | **14.3** | **1.1** | **7.2** | **1.1** | **3.2** | ***4.3*** | ***78.0*** | ***1.1*** | ***-61.7*** |
| **Jun-99** | **0.8** | **435.5** | **1167.4** | **36.9** | **2.6** | **14.7** | **0.9** | **0.9** | ***0.7*** | ***72.7*** | ***0.9*** | ***-19.3*** |
| **Jul-99** | **0.9** | **436.8** | **1221.0** | **57.7** | **31.5** | **29.9** | **1.4** | **2.0** | ***0.1*** | ***61.7*** | ***1.9*** | ***57.2*** |
| **Aug-99** | **1.2** | **444.2** | **1363.8** | **38.1** | **61.5** | **52.7** | **3.2** | **9.3** | ***0.1*** | ***62.7*** | ***6.0*** | ***86.3*** |
| **Sep-99** | **1.4** | **455.5** | **1456.8** | **23.7** | **35.4** | **38.9** | **5.8** | **19.0** | ***0.2*** | ***62.1*** | ***4.4*** | ***21.1*** |
| **Oct-99** | **1.6** | **478.4** | **1556.9** | **71.2** | **68.8** | **121.6** | **13.3** | **46.1** | ***4.3*** | ***72.5*** | ***-88.8*** | ***156.2*** |
| **Nov-99** | **1.8** | **505.1** | **1628.1** | **0.7** | **10.5** | **37.0** | **10.1** | **58.4** | ***4.6*** | ***68.9*** | ***-6.6*** | ***-77.8*** |
| **Dec-99** | **1.6** | **472.5** | **1536.3** | **0.0** | **1.1** | **6.9** | **3.0** | **42.0** | ***4.6*** | ***68.3*** | ***-1.3*** | ***-105.5*** |
| **Jan-00** | **1.4** | **453.7** | **1445.1** | **0.0** | **1.1** | **6.4** | **1.3** | **28.8** | ***4.6*** | ***68.5*** | ***-1.3*** | ***-93.0*** |
| **Feb-00** | **1.2** | **443.8** | **1358.6** | **0.0** | **1.0** | **5.7** | **1.3** | **14.5** | ***5.4*** | ***68.2*** | ***-1.3*** | ***-80.1*** |
| **Mar-00** | **1.0** | **438.4** | **1267.0** | **3.5** | **0.9** | **5.8** | **1.3** | **4.5** | ***5.9*** | ***76.9*** | ***1.1*** | ***-75.9*** |
| **Apr-00** | **0.8** | **435.5** | **1164.6** | **28.7** | **1.0** | **5.3** | **1.1** | **1.7** | ***6.5*** | ***73.0*** | ***1.0*** | ***-45.2*** |
| **May-00** | **0.8** | **435.2** | **1151.2** | **46.5** | **3.0** | **6.3** | **1.9** | **1.4** | ***4.3*** | ***78.0*** | ***2.3*** | ***-25.5*** |
| **Jun-00** | **0.7** | **434.7** | **1126.5** | **18.8** | **0.9** | **7.1** | **1.4** | **0.6** | ***0.7*** | ***72.7*** | ***1.1*** | ***-46.1*** |
| **Jul-00** | **0.8** | **435.3** | **1156.9** | **69.4** | **8.3** | **55.2** | **3.3** | **1.7** | ***0.1*** | ***61.7*** | ***4.7*** | ***74.1*** |
| **Aug-00** | **1.0** | **438.3** | **1263.6** | **55.6** | **27.0** | **107.0** | **10.3** | **4.6** | ***0.1*** | ***62.7*** | ***13.4*** | ***135.6*** |
| **Sep-00** | **1.4** | **453.2** | **1441.8** | **48.8** | **29.4** | **118.6** | **12.8** | **16.1** | ***0.2*** | ***62.1*** | ***14.6*** | ***133.1*** |
| **Oct-00** | **1.6** | **470.5** | **1529.0** | **16.6** | **24.7** | **80.3** | **17.6** | **37.6** | ***4.3*** | ***72.5*** | ***-32.0*** | ***22.5*** |
| **Nov-00** | **1.6** | **466.6** | **1512.8** | **20.5** | **17.9** | **26.5** | **7.0** | **39.1** | ***4.6*** | ***68.9*** | ***-24.6*** | ***-43.6*** |
| **Dec-00** | **1.4** | **454.0** | **1447.4** | **9.3** | **13.3** | **7.1** | **2.7** | **30.9** | ***4.6*** | ***68.3*** | ***-11.0*** | ***-72.5*** |
| **1-Jan** | **1.3** | **446.0** | **1382.9** | **0.0** | **1.2** | **6.3** | **1.4** | **22.6** | ***4.6*** | ***68.5*** | ***-1.3*** | ***-86.8*** |
| **1-Feb** | **1.1** | **440.5** | **1311.1** | **18.4** | **2.2** | **5.6** | **1.5** | **17.8** | ***5.4*** | ***68.2*** | ***-19.8*** | ***-63.8*** |
| **1-Mar** | **1.0** | **438.3** | **1266.0** | **54.3** | **20.3** | **5.8** | **2.0** | **9.7** | ***5.9*** | ***76.9*** | ***2.1*** | ***-10.1*** |
| **1-Apr** | **1.0** | **437.8** | **1251.6** | **11.6** | **13.2** | **5.6** | **2.7** | **7.4** | ***6.5*** | ***73.0*** | ***2.6*** | ***-53.9*** |
| **1-May** | **0.9** | **436.9** | **1222.9** | **54.2** | **35.0** | **8.2** | **4.2** | **3.2** | ***4.3*** | ***78.0*** | ***4.4*** | ***16.3*** |
| **1-Jun** | **1.0** | **437.4** | **1239.2** | **32.5** | **55.2** | **19.0** | **5.0** | **1.4** | ***0.7*** | ***72.7*** | ***5.3*** | ***37.1*** |
| **1-Jul** | **1.2** | **443.3** | **1352.8** | **61.3** | **86.9** | **86.4** | **11.6** | **10.7** | ***0.1*** | ***61.7*** | ***13.7*** | ***175.7*** |
| **1-Aug** | **1.7** | **485.7** | **1579.6** | **62.5** | **88.2** | **162.8** | **17.6** | **20.0** | ***0.1*** | ***62.7*** | ***19.6*** | ***250.3*** |

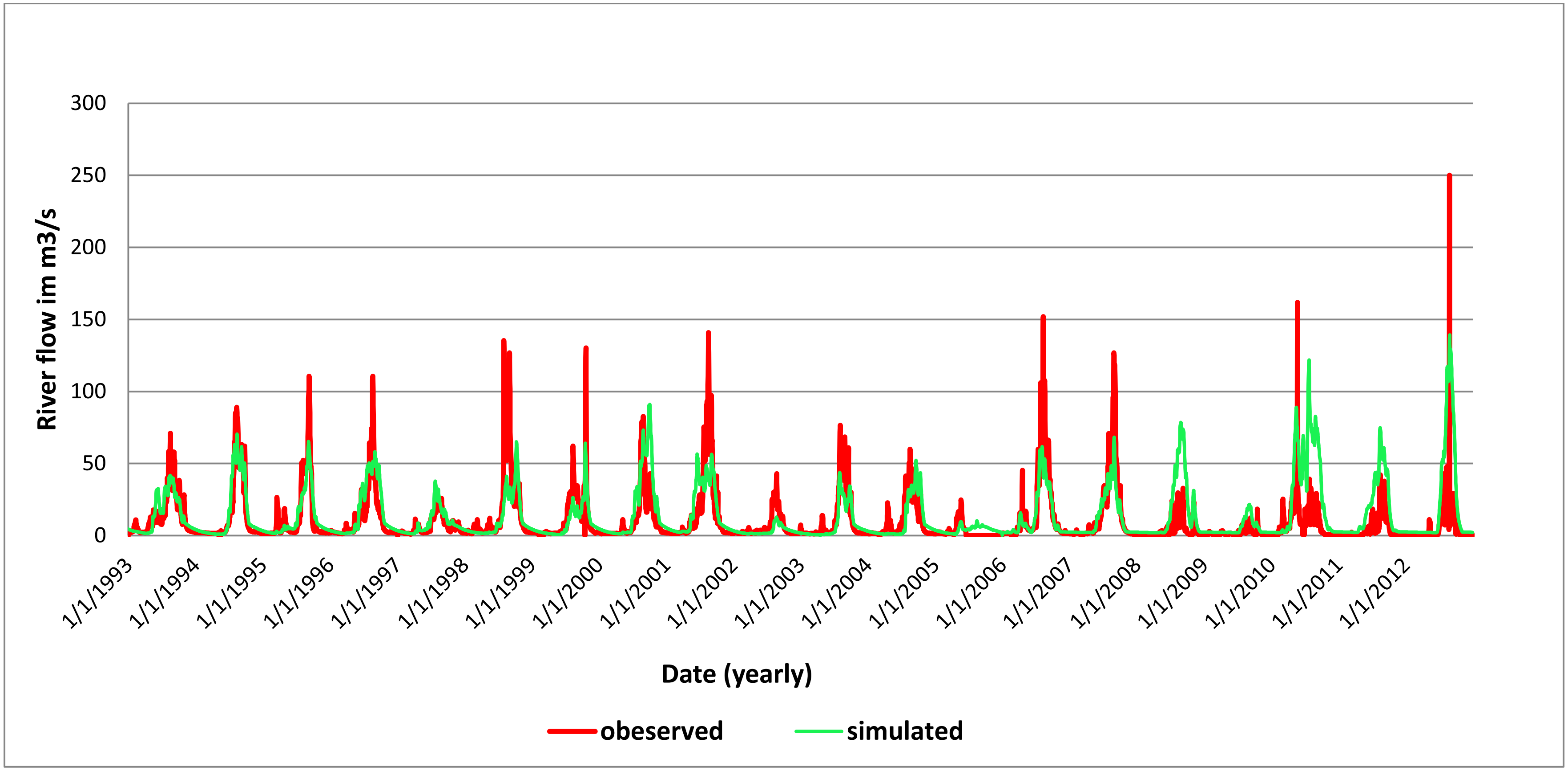
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-Sep** | **2.3** | **648.8** | **1809.0** | **31.8** | **74.3** | **108.8** | **25.9** | **65.2** | ***0.2*** | ***62.1*** | ***29.5*** | ***116.9*** |
| **1-Oct** | **2.2** | **607.0** | **1772.8** | **0.1** | **13.4** | **72.6** | **12.5** | **63.8** | ***4.3*** | ***72.5*** | ***-5.4*** | ***-49.3*** |
| **1-Nov** | **1.9** | **533.1** | **1680.7** | **0.0** | **1.1** | **13.3** | **2.3** | **37.6** | ***4.6*** | ***68.9*** | ***-1.3*** | ***-95.4*** |
| **1-Dec** | **1.7** | **494.2** | **1602.4** | **0.4** | **1.1** | **6.7** | **1.3** | **32.6** | ***4.6*** | ***68.3*** | ***-1.8*** | ***-96.0*** |
| **2-Jan** | **1.6** | **468.6** | **1521.2** | **2.6** | **1.4** | **6.3** | **1.3** | **25.8** | ***4.6*** | ***68.5*** | ***-3.9*** | ***-87.2*** |
| **2-Feb** | **1.4** | **454.1** | **1447.9** | **9.5** | **1.2** | **5.6** | **1.3** | **16.9** | ***5.4*** | ***68.2*** | ***-10.7*** | ***-72.9*** |
| **2-Mar** | **1.3** | **447.1** | **1393.4** | **19.9** | **3.6** | **5.8** | **1.3** | **10.7** | ***5.9*** | ***76.9*** | ***1.3*** | ***-63.0*** |
| **2-Apr** | **1.2** | **442.9** | **1347.6** | **25.8** | **2.7** | **5.5** | **1.3** | **5.9** | ***6.5*** | ***73.0*** | ***1.3*** | ***-50.1*** |
| **2-May** | **1.1** | **439.5** | **1292.0** | **17.5** | **3.1** | **5.6** | **1.3** | **2.9** | ***4.3*** | ***78.0*** | ***1.3*** | ***-57.6*** |
| **2-Jun** | **1.0** | **437.6** | **1244.5** | **21.8** | **7.4** | **5.3** | **1.3** | **2.9** | ***0.7*** | ***72.7*** | ***1.3*** | ***-40.4*** |
| **2-Jul** | **0.9** | **436.7** | **1216.2** | **44.6** | **16.6** | **12.0** | **1.4** | **4.1** | ***0.1*** | ***61.7*** | ***1.3*** | ***8.6*** |
| **2-Aug** | **1.0** | **438.3** | **1266.0** | **46.6** | **48.8** | **36.4** | **2.2** | **5.0** | ***0.1*** | ***62.7*** | ***3.2*** | ***67.2*** |
| **2-Sep** | **1.2** | **443.8** | **1359.0** | **23.6** | **60.3** | **40.7** | **4.5** | **7.0** | ***0.2*** | ***62.1*** | ***4.6*** | ***59.9*** |
| **2-Oct** | **1.2** | **441.3** | **1324.1** | **0.1** | **6.5** | **26.2** | **2.4** | **3.8** | ***4.3*** | ***72.5*** | ***-1.4*** | ***-46.6*** |
| **2-Nov** | **1.0** | **437.3** | **1238.2** | **0.0** | **1.0** | **8.2** | **1.3** | **2.8** | ***4.6*** | ***68.9*** | ***-1.3*** | ***-65.8*** |
| **2-Dec** | **0.8** | **435.3** | **1158.4** | **5.4** | **1.3** | **6.1** | **1.3** | **2.6** | ***4.6*** | ***68.3*** | ***-6.7*** | ***-61.4*** |
| **3-Jan** | **0.7** | **434.1** | **1101.4** | **9.5** | **1.0** | **5.8** | **1.3** | **1.7** | ***4.6*** | ***68.5*** | ***-10.6*** | ***-57.4*** |
| **3-Feb** | **0.6** | **433.0** | **1053.1** | **5.8** | **0.9** | **5.7** | **1.0** | **0.7** | ***5.4*** | ***68.2*** | ***-6.8*** | ***-60.9*** |
| **3-Mar** | **0.5** | **431.0** | **991.9** | **29.2** | **2.7** | **8.1** | **1.1** | **0.5** | ***5.9*** | ***76.9*** | ***1.1*** | ***-42.4*** |
| **3-Apr** | **0.4** | **429.6** | **959.8** | **59.8** | **9.5** | **6.5** | **0.9** | **0.5** | ***6.5*** | ***73.0*** | ***1.3*** | ***-2.7*** |
| **3-May** | **0.4** | **429.1** | **950.3** | **14.4** | **9.9** | **7.9** | **1.7** | **0.7** | ***4.3*** | ***78.0*** | ***1.9*** | ***-48.8*** |
| **3-Jun** | **0.2** | **425.8** | **894.6** | **24.7** | **19.5** | **7.4** | **1.6** | **0.9** | ***0.7*** | ***72.7*** | ***1.0*** | ***-21.7*** |
| **3-Jul** | **0.4** | **429.5** | **957.1** | **106.2** | **64.8** | **48.1** | **11.2** | **0.7** | ***0.1*** | ***61.7*** | ***16.1*** | ***172.6*** |
| **3-Aug** | **0.9** | **435.9** | **1183.6** | **54.8** | **79.1** | **104.1** | **26.4** | **2.0** | ***0.1*** | ***62.7*** | ***28.0*** | ***201.3*** |
| **3-Sep** | **1.2** | **441.9** | **1333.2** | **30.1** | **54.3** | **93.2** | **27.2** | **5.0** | ***0.2*** | ***62.1*** | ***23.2*** | ***133.6*** |
| **3-Oct** | **1.2** | **442.7** | **1344.7** | **0.1** | **13.9** | **24.5** | **7.9** | **4.7** | ***4.3*** | ***72.5*** | ***-5.8*** | ***-37.4*** |
| **3-Nov** | **1.0** | **438.4** | **1267.0** | **1.6** | **1.2** | **6.4** | **1.5** | **2.9** | ***4.6*** | ***68.9*** | ***-2.9*** | ***-65.9*** |
| **3-Dec** | **0.9** | **436.7** | **1215.7** | **14.8** | **4.4** | **6.4** | **1.6** | **1.6** | ***4.6*** | ***68.3*** | ***-16.3*** | ***-47.3*** |
| **4-Jan** | **0.8** | **435.7** | **1176.0** | **19.8** | **3.2** | **6.1** | **1.5** | **0.4** | ***4.6*** | ***68.5*** | ***-21.3*** | ***-42.8*** |
| **4-Feb** | **0.8** | **434.8** | **1135.1** | **0.8** | **1.3** | **6.4** | **1.4** | **0.0** | ***5.4*** | ***68.2*** | ***-2.1*** | ***-63.8*** |
| **4-Mar** | **0.6** | **432.8** | **1046.5** | **9.2** | **0.9** | **9.0** | **1.2** | **0.0** | ***5.9*** | ***76.9*** | ***1.1*** | ***-62.7*** |
| **4-Apr** | **0.5** | **432.5** | **1035.8** | **60.2** | **11.7** | **12.6** | **2.6** | **0.0** | ***6.5*** | ***73.0*** | ***2.7*** | ***7.6*** |
| **4-May** | **0.5** | **432.2** | **1026.0** | **0.6** | **1.6** | **7.6** | **1.3** | **0.0** | ***4.3*** | ***78.0*** | ***1.2*** | ***-71.3*** |
| **4-Jun** | **0.4** | **430.0** | **968.0** | **27.3** | **2.9** | **6.1** | **1.0** | **0.0** | ***0.7*** | ***72.7*** | ***1.0*** | ***-36.2*** |
| **4-Jul** | **0.4** | **429.5** | **956.6** | **47.6** | **12.5** | **22.5** | **2.5** | **0.0** | ***0.1*** | ***61.7*** | ***2.6*** | ***23.4*** |
| **4-Aug** | **0.7** | **434.7** | **1128.9** | **66.3** | **34.4** | **79.7** | **12.7** | **0.8** | ***0.1*** | ***62.7*** | ***13.7*** | ***130.4*** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-Sep | 1.0 | 437.0 | 1228.1 | 47.6 | 34.5 | 93.5 | 12.5 | 5.1 | 0.2 | 62.1 | 13.2 | 121.4 |
| 4-Oct | 1.1 | 440.0 | 1302.5 | 12.4 | 19.3 | 68.7 | 10.2 | 4.8 | 4.3 | 72.5 | -22.5 | 28.9 |
| 4-Nov | 1.0 | 438.0 | 1256.9 | 5.8 | 1.2 | 10.2 | 3.0 | 1.8 | 4.6 | 68.9 | -7.3 | -56.6 |
| 4-Dec | 0.9 | 436.3 | 1202.3 | 0.0 | 1.0 | 6.7 | 1.3 | 1.1 | 4.6 | 68.3 | -1.4 | -65.0 |
| 5-Jan | 0.7 | 434.7 | 1128.4 | 22.0 | 0.9 | 6.3 | 1.3 | 1.0 | 11.6 | 68.5 | -23.4 | -50.5 |
| 5-Feb | 0.6 | 433.3 | 1063.3 | 8.1 | 0.8 | 5.7 | 1.3 | 0.3 | 13.5 | 68.2 | -9.2 | -66.3 |
| 5-Mar | 0.5 | 432.3 | 1028.8 | 36.7 | 1.8 | 5.8 | 1.3 | 0.2 | 14.9 | 76.9 | 1.3 | -46.3 |
| 5-Apr | 0.4 | 430.3 | 974.9 | 28.8 | 4.9 | 5.5 | 1.2 | 0.0 | 16.2 | 73.0 | 1.2 | -48.8 |
| 5-May | 0.6 | 432.7 | 1042.8 | 66.9 | 43.9 | 11.2 | 15.2 | 0.2 | 10.8 | 78.0 | 15.4 | 48.3 |
| 5-Jun | 0.6 | 433.5 | 1071.8 | 16.9 | 21.2 | 37.7 | 5.3 | 0.2 | 2.1 | 72.7 | 5.1 | 5.8 |
| 5-Jul | 0.6 | 433.6 | 1077.4 | 56.7 | 71.8 | 51.4 | 8.3 | 0.4 | 0.7 | 61.7 | 9.3 | 126.3 |
| 5-Aug | 1.0 | 437.7 | 1248.8 | 51.5 | 138.5 | 53.2 | 15.7 | 6.7 | 0.7 | 62.7 | 19.4 | 192.7 |
| 5-Sep | 1.4 | 452.1 | 1434.2 | 55.6 | 121.5 | 25.9 | 20.4 | 13.7 | 0.9 | 62.1 | 20.1 | 146.5 |
| 5-Oct | 1.5 | 459.0 | 1476.5 | 2.1 | 70.8 | 10.0 | 11.2 | 13.0 | 11.0 | 72.5 | -9.9 | -5.8 |
| 5-Nov | 1.3 | 448.7 | 1408.1 | 1.0 | 8.8 | 6.4 | 2.3 | 9.3 | 11.6 | 68.9 | -2.3 | -72.2 |
| 5-Dec | 1.2 | 441.5 | 1327.0 | 0.0 | 1.5 | 6.3 | 1.3 | 6.5 | 11.6 | 68.3 | -1.3 | -77.2 |
| 6-Jan | 1.0 | 438.1 | 1260.8 | 0.4 | 1.0 | 6.0 | 1.3 | 3.2 | 11.6 | 68.5 | -1.7 | -74.5 |
| 6-Feb | 0.9 | 436.2 | 1198.5 | 14.7 | 0.8 | 5.3 | 1.3 | 1.0 | 13.5 | 68.2 | -15.7 | -60.9 |
| 6-Mar | 0.8 | 435.1 | 1148.8 | 30.0 | 0.8 | 5.4 | 1.1 | 1.0 | 14.9 | 76.9 | 1.1 | -55.5 |
| 6-Apr | 0.9 | 436.6 | 1213.3 | 62.9 | 1.0 | 6.1 | 4.2 | 3.3 | 16.2 | 73.0 | 4.7 | -18.0 |
| 6-May | 1.1 | 439.0 | 1281.9 | 23.0 | 1.0 | 5.9 | 7.6 | 6.0 | 10.8 | 78.0 | 7.4 | -57.6 |
| 6-Jun | 1.0 | 437.8 | 1250.7 | 42.5 | 1.0 | 9.5 | 2.6 | 2.9 | 2.1 | 72.7 | 2.6 | -22.2 |
| 6-Jul | 1.2 | 441.9 | 1333.7 | 89.3 | 15.3 | 78.9 | 28.4 | 13.6 | 0.7 | 61.7 | 30.9 | 138.5 |
| 6-Aug | 1.8 | 504.7 | 1627.2 | 44.1 | 46.4 | 184.6 | 46.7 | 97.7 | 0.7 | 62.7 | 50.2 | 164.3 |
| 6-Sep | 2.2 | 622.3 | 1787.0 | 34.3 | 47.6 | 107.0 | 26.6 | 49.7 | 0.9 | 62.1 | 24.7 | 101.0 |
| 6-Oct | 2.2 | 643.6 | 1805.0 | 8.7 | 29.8 | 26.2 | 9.1 | 11.5 | 11.0 | 72.5 | -14.2 | -24.9 |
| 6-Nov | 2.0 | 556.2 | 1714.9 | 0.1 | 3.1 | 8.7 | 2.6 | 45.3 | 11.6 | 68.9 | -2.1 | -111.8 |
| 6-Dec | 1.8 | 501.4 | 1619.7 | 2.9 | 0.8 | 6.3 | 1.3 | 28.3 | 11.6 | 68.3 | -4.3 | -96.7 |
| 7-Jan | 1.6 | 474.0 | 1541.8 | 3.2 | 0.8 | 6.0 | 1.3 | 15.5 | 11.6 | 68.5 | -4.5 | -84.2 |
| 7-Feb | 1.5 | 462.4 | 1493.8 | 16.6 | 11.7 | 5.4 | 1.3 | 15.4 | 13.5 | 68.2 | -17.9 | -62.1 |
| 7-Mar | 1.3 | 449.7 | 1416.2 | 12.9 | 4.5 | 5.5 | 1.3 | 11.0 | 14.9 | 76.9 | 1.2 | -78.8 |
| 7-Apr | 1.3 | 446.0 | 1383.4 | 33.6 | 6.6 | 5.2 | 1.3 | 4.4 | 16.2 | 73.0 | 1.2 | -47.0 |
| 7-May | 1.2 | 442.2 | 1337.5 | 53.3 | 6.4 | 11.0 | 1.6 | 3.6 | 10.8 | 78.0 | 1.7 | -20.0 |
| 7-Jun | 1.3 | 446.2 | 1384.8 | 74.1 | 31.4 | 45.6 | 11.7 | 4.1 | 2.1 | 72.7 | 14.4 | 86.5 |
| 7-Jul | 1.5 | 460.9 | 1486.3 | 76.5 | 89.3 | 81.2 | 33.1 | 16.7 | 0.7 | 61.7 | 36.2 | 204.1 |
| 7-Aug | 1.9 | 529.5 | 1674.8 | 56.8 | 115.9 | 168.4 | 59.2 | 50.4 | 0.7 | 62.7 | 64.1 | 291.5 |

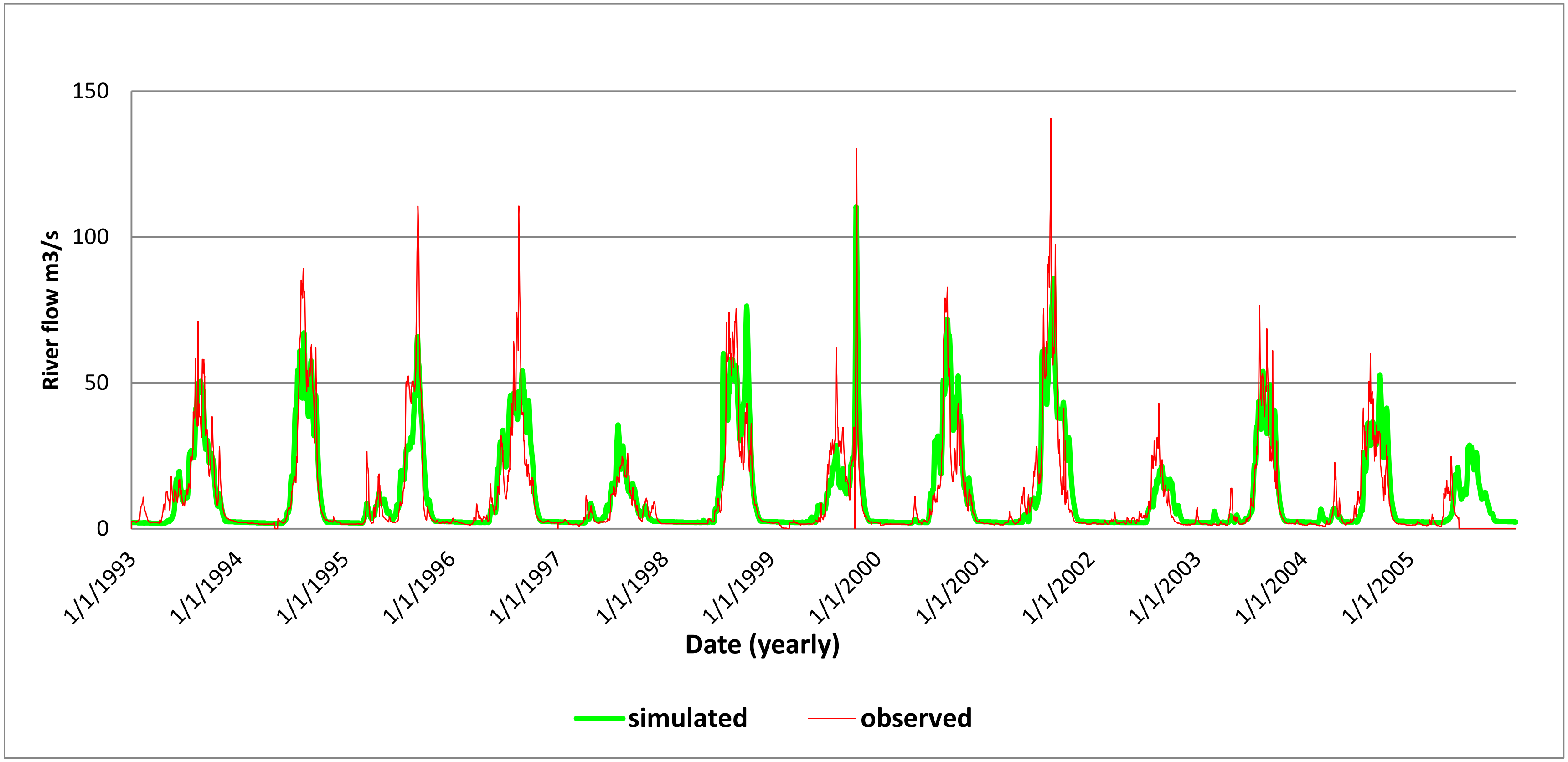
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7-Sep** | **2.3** | **685.9** | **1835.7** | **29.5** | **60.8** | **130.8** | **57.0** | **84.7** | ***0.9*** | ***62.1*** | ***51.2*** | ***124.7*** |
| **7-Oct** | **2.4** | **735.0** | **1865.1** | **6.9** | **14.9** | **38.6** | **13.7** | **85.8** | ***11.0*** | ***72.5*** | ***-16.2*** | ***-99.7*** |
| **7-Nov** | **2.1** | **599.6** | **1765.4** | **0.5** | **1.0** | **6.7** | **1.9** | **58.8** | ***11.6*** | ***68.9*** | ***-1.9*** | ***-129.6*** |
| **7-Dec** | **1.9** | **520.0** | **1658.1** | **0.0** | **0.8** | **6.2** | **1.3** | **38.3** | ***11.6*** | ***68.3*** | ***-1.3*** | ***-109.7*** |
| **8-Jan** | **1.6** | **475.2** | **1546.0** | **0.1** | **0.8** | **5.9** | **1.3** | **25.6** | ***11.6*** | ***68.5*** | ***-1.4*** | ***-97.5*** |
| **8-Feb** | **1.5** | **457.4** | **1467.6** | **0.1** | **0.8** | **5.2** | **1.3** | **2.9** | ***13.5*** | ***68.2*** | ***-1.3*** | ***-77.2*** |
| **8-Mar** | **1.3** | **446.1** | **1384.3** | **0.1** | **0.8** | **5.3** | **1.3** | **2.4** | ***14.9*** | ***76.9*** | ***1.2*** | ***-86.7*** |
| **8-Apr** | **1.1** | **440.1** | **1304.0** | **6.4** | **0.8** | **4.9** | **1.2** | **2.3** | ***16.2*** | ***73.0*** | ***1.0*** | ***-78.4*** |
| **8-May** | **1.0** | **438.2** | **1261.7** | **30.2** | **0.8** | **8.4** | **1.1** | **2.8** | ***10.8*** | ***78.0*** | ***1.1*** | ***-51.1*** |
| **8-Jun** | **1.0** | **437.1** | **1229.1** | **39.9** | **3.6** | **27.6** | **1.0** | **3.0** | ***2.1*** | ***72.7*** | ***1.0*** | ***-5.8*** |
| **8-Jul** | **1.1** | **439.1** | **1283.3** | **98.6** | **27.8** | **98.2** | **7.1** | **6.5** | ***0.7*** | ***61.7*** | ***9.3*** | ***165.1*** |
| **8-Aug** | **1.5** | **458.7** | **1475.1** | **89.4** | **54.5** | **159.1** | **45.3** | **2.4** | ***0.7*** | ***62.7*** | ***52.2*** | ***289.5*** |
| **8-Sep** | **1.8** | **509.2** | **1636.8** | **38.9** | **43.6** | **120.9** | **63.7** | **2.5** | ***0.9*** | ***62.1*** | ***62.5*** | ***200.4*** |
| **8-Oct** | **1.8** | **501.8** | **1620.6** | **20.0** | **9.6** | **31.8** | **15.3** | **2.6** | ***11.0*** | ***72.5*** | ***-28.8*** | ***-16.0*** |
| **8-Nov** | **1.8** | **504.1** | **1625.9** | **84.7** | **26.8** | **39.6** | **19.9** | **6.8** | ***11.6*** | ***68.9*** | ***-109.9*** | ***88.9*** |
| **8-Dec** | **1.6** | **477.0** | **1552.4** | **0.0** | **0.9** | **6.9** | **8.6** | **2.4** | ***11.6*** | ***68.3*** | ***-2.5*** | ***-71.9*** |
| **9-Jan** | **1.5** | **462.0** | **1491.9** | **15.3** | **1.4** | **6.2** | **1.8** | **2.6** | ***11.6*** | ***68.5*** | ***-16.9*** | ***-58.2*** |
| **9-Feb** | **1.4** | **452.8** | **1438.9** | **1.3** | **0.8** | **5.6** | **1.3** | **16.2** | ***13.5*** | ***68.2*** | ***-2.6*** | ***-88.9*** |
| **9-Mar** | **1.2** | **443.5** | **1355.2** | **17.0** | **0.9** | **5.7** | **1.3** | **8.6** | ***14.9*** | ***76.9*** | ***1.3*** | ***-75.4*** |
| **9-Apr** | **1.1** | **440.5** | **1311.6** | **21.4** | **1.0** | **5.5** | **1.3** | **10.5** | ***16.2*** | ***73.0*** | ***1.3*** | ***-70.4*** |
| **9-May** | **0.9** | **437.0** | **1226.7** | **36.6** | **0.9** | **5.7** | **1.3** | **4.3** | ***10.8*** | ***78.0*** | ***1.4*** | ***-48.6*** |
| **9-Jun** | **0.8** | **435.5** | **1165.5** | **32.9** | **0.8** | **5.2** | **1.3** | **2.0** | ***2.1*** | ***72.7*** | ***1.5*** | ***-36.5*** |
| **9-Jul** | **0.8** | **435.0** | **1143.6** | **85.0** | **8.9** | **15.0** | **10.4** | **3.8** | ***0.7*** | ***61.7*** | ***12.6*** | ***55.3*** |
| **9-Aug** | **1.0** | **437.7** | **1248.8** | **45.1** | **15.3** | **71.6** | **35.4** | **5.2** | ***0.7*** | ***62.7*** | ***37.5*** | ***101.0*** |
| **9-Sep** | **1.1** | **440.9** | **1318.3** | **34.3** | **12.8** | **77.0** | **30.8** | **4.6** | ***0.9*** | ***62.1*** | ***28.2*** | ***84.7*** |
| **9-Oct** | **1.2** | **441.7** | **1329.8** | **32.8** | **9.9** | **28.6** | **17.1** | **4.6** | ***11.0*** | ***72.5*** | ***-48.0*** | ***-1.5*** |
| **9-Nov** | **1.1** | **439.6** | **1294.8** | **2.4** | **0.8** | **7.1** | **3.1** | **2.5** | ***11.6*** | ***68.9*** | ***-5.4*** | ***-69.6*** |
| **9-Dec** | **1.0** | **437.4** | **1239.2** | **7.3** | **0.8** | **6.0** | **1.4** | **2.3** | ***11.6*** | ***68.3*** | ***-8.7*** | ***-66.6*** |
| **10-Jan** | **0.9** | **435.9** | **1186.5** | **2.1** | **0.8** | **5.7** | **1.4** | **2.3** | ***11.6*** | ***68.5*** | ***-3.5*** | ***-72.4*** |
| **10-Feb** | **0.8** | **435.2** | **1152.2** | **41.8** | **4.0** | **5.2** | **5.8** | **3.6** | ***13.5*** | ***68.2*** | ***-47.6*** | ***-28.5*** |
| **10-Mar** | **0.8** | **435.7** | **1176.5** | **17.7** | **9.7** | **9.2** | **6.7** | **8.3** | ***14.9*** | ***76.9*** | ***6.6*** | ***-56.9*** |
| **10-Apr** | **0.8** | **435.6** | **1170.8** | **44.0** | **30.4** | **30.1** | **4.2** | **8.3** | ***16.2*** | ***73.0*** | ***4.0*** | ***11.1*** |
| **10-May** | **1.0** | **437.6** | **1244.5** | **46.3** | **24.8** | **86.2** | **10.1** | **14.3** | ***10.8*** | ***78.0*** | ***11.0*** | ***65.2*** |
| **10-Jun** | **1.1** | **440.8** | **1315.5** | **28.9** | **7.2** | **43.9** | **7.6** | **18.5** | ***2.1*** | ***72.7*** | ***6.9*** | ***-6.3*** |
| **10-Jul** | **1.3** | **445.6** | **1379.1** | **76.2** | **45.7** | **115.5** | **31.1** | **29.9** | ***0.7*** | ***61.7*** | ***33.0*** | ***178.0*** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10-Aug** | **1.7** | **492.6** | **1598.4** | **59.9** | **102.5** | **184.7** | **44.3** | **51.6** | ***0.7*** | ***62.7*** | ***48.0*** | ***280.2*** |
| **10-Sep** | **2.2** | **647.3** | **1807.9** | **52.7** | **73.2** | **158.4** | **40.6** | **77.1** | ***0.9*** | ***62.1*** | ***40.8*** | ***185.1*** |
| **10-Oct** | **2.3** | **697.3** | **1843.0** | **5.7** | **14.8** | **46.4** | **22.9** | **76.7** | ***11.0*** | ***72.5*** | ***-25.7*** | ***-73.3*** |
| **10-Nov** | **2.2** | **611.5** | **1777.1** | **10.1** | **1.4** | **11.5** | **5.0** | **57.8** | ***11.6*** | ***68.9*** | ***-12.5*** | ***-112.9*** |
| **10-Dec** | **2.0** | **547.0** | **1702.1** | **4.4** | **0.8** | **7.1** | **1.8** | **51.2** | ***11.6*** | ***68.3*** | ***-6.1*** | ***-117.1*** |
| **11-Jan** | **1.7** | **491.3** | **1594.8** | **0.0** | **0.8** | **6.7** | **1.3** | **41.1** | ***11.6*** | ***68.5*** | ***-1.4*** | ***-112.2*** |
| **11-Feb** | **1.6** | **471.4** | **1532.2** | **9.0** | **0.8** | **6.0** | **1.3** | **29.6** | ***13.5*** | ***68.2*** | ***-10.2*** | ***-94.3*** |
| **11-Mar** | **1.5** | **457.3** | **1467.2** | **43.5** | **0.9** | **6.1** | **1.5** | **26.1** | ***14.9*** | ***76.9*** | ***1.5*** | ***-65.9*** |
| **11-Apr** | **1.3** | **447.1** | **1393.9** | **9.7** | **0.8** | **8.4** | **1.3** | **18.2** | ***16.2*** | ***73.0*** | ***1.3*** | ***-87.2*** |
| **11-May** | **1.2** | **441.3** | **1324.1** | **34.3** | **11.4** | **19.3** | **1.3** | **14.2** | ***10.8*** | ***78.0*** | ***1.4*** | ***-36.5*** |
| **11-Jun** | **1.1** | **439.9** | **1300.6** | **41.0** | **23.4** | **50.8** | **1.6** | **12.3** | ***2.1*** | ***72.7*** | ***2.0*** | ***30.0*** |
| **11-Jul** | **1.2** | **443.5** | **1354.7** | **76.9** | **38.7** | **102.1** | **14.0** | **15.8** | ***0.7*** | ***61.7*** | ***17.9*** | ***157.4*** |
| **11-Aug** | **1.5** | **458.5** | **1473.7** | **69.9** | **83.5** | **228.4** | **36.8** | **31.0** | ***0.7*** | ***62.7*** | ***36.7*** | ***324.2*** |
| **11-Sep** | **1.9** | **516.6** | **1651.6** | **29.3** | **57.4** | **123.6** | **26.8** | **51.8** | ***0.9*** | ***62.1*** | ***27.3*** | ***122.7*** |
| **11-Oct** | **1.9** | **522.6** | **1662.8** | **3.0** | **10.2** | **27.5** | **10.1** | **46.1** | ***11.0*** | ***72.5*** | ***-8.7*** | ***-83.3*** |
| **11-Nov** | **1.7** | **488.4** | **1587.2** | **2.3** | **1.5** | **7.7** | **1.8** | **34.1** | ***11.6*** | ***68.9*** | ***-3.6*** | ***-101.8*** |
| **11-Dec** | **1.6** | **469.4** | **1524.4** | **0.0** | **0.8** | **6.9** | **1.3** | **26.8** | ***11.6*** | ***68.3*** | ***-1.3*** | ***-97.6*** |
| **12-Jan** | **1.4** | **455.9** | **1459.2** | **0.0** | **0.8** | **6.5** | **1.3** | **21.1** | ***11.6*** | ***68.5*** | ***-1.3*** | ***-92.5*** |
| **12-Feb** | **1.2** | **442.8** | **1346.6** | **1.4** | **0.8** | **5.8** | **1.3** | **15.5** | ***13.5*** | ***68.2*** | ***-2.6*** | ***-88.0*** |
| **12-Mar** | **1.0** | **438.3** | **1265.1** | **8.4** | **0.8** | **5.9** | **1.3** | **10.2** | ***14.9*** | ***76.9*** | ***1.3*** | ***-85.6*** |
| **12-Apr** | **0.9** | **436.9** | **1224.3** | **37.6** | **1.0** | **5.5** | **1.3** | **7.9** | ***16.2*** | ***73.0*** | ***1.3*** | ***-51.7*** |
| **12-May** | **0.8** | **435.7** | **1174.6** | **8.0** | **1.2** | **5.6** | **1.3** | **7.0** | ***10.8*** | ***78.0*** | ***1.3*** | ***-79.7*** |
| **12-Jun** | **0.7** | **434.0** | **1095.8** | **21.5** | **1.8** | **5.3** | **1.3** | **5.2** | ***2.1*** | ***72.7*** | ***1.0*** | ***-50.3*** |
| **12-Jul** | **0.8** | **435.3** | **1156.9** | **126.9** | **67.3** | **32.8** | **19.4** | **8.4** | ***0.7*** | ***61.7*** | ***20.2*** | ***176.4*** |
| **12-Aug** | **1.3** | **449.0** | **1410.5** | **59.4** | **114.9** | **158.1** | **41.5** | **25.1** | ***0.7*** | ***62.7*** | ***45.5*** | ***289.6*** |
| **12-Sep** | **1.8** | **497.4** | **1610.4** | **13.3** | **63.1** | **141.5** | **18.3** | **42.3** | ***0.9*** | ***62.1*** | ***18.8*** | ***131.3*** |
| **12-Oct** | **1.9** | **515.3** | **1649.0** | **0.5** | **9.9** | **27.2** | **6.8** | **41.4** | ***11.0*** | ***72.5*** | ***-2.9*** | ***-85.0*** |
| **12-Nov** | **1.7** | **479.9** | **1561.9** | **0.1** | **0.8** | **6.1** | **1.9** | **29.1** | ***11.6*** | ***68.9*** | ***-1.4*** | ***-101.4*** |
| **12-Dec** | **1.5** | **460.4** | **1484.0** | **5.0** | **0.8** | **5.8** | **1.3** | **23.8** | ***11.6*** | ***68.3*** | ***-5.9*** | ***-90.9*** |

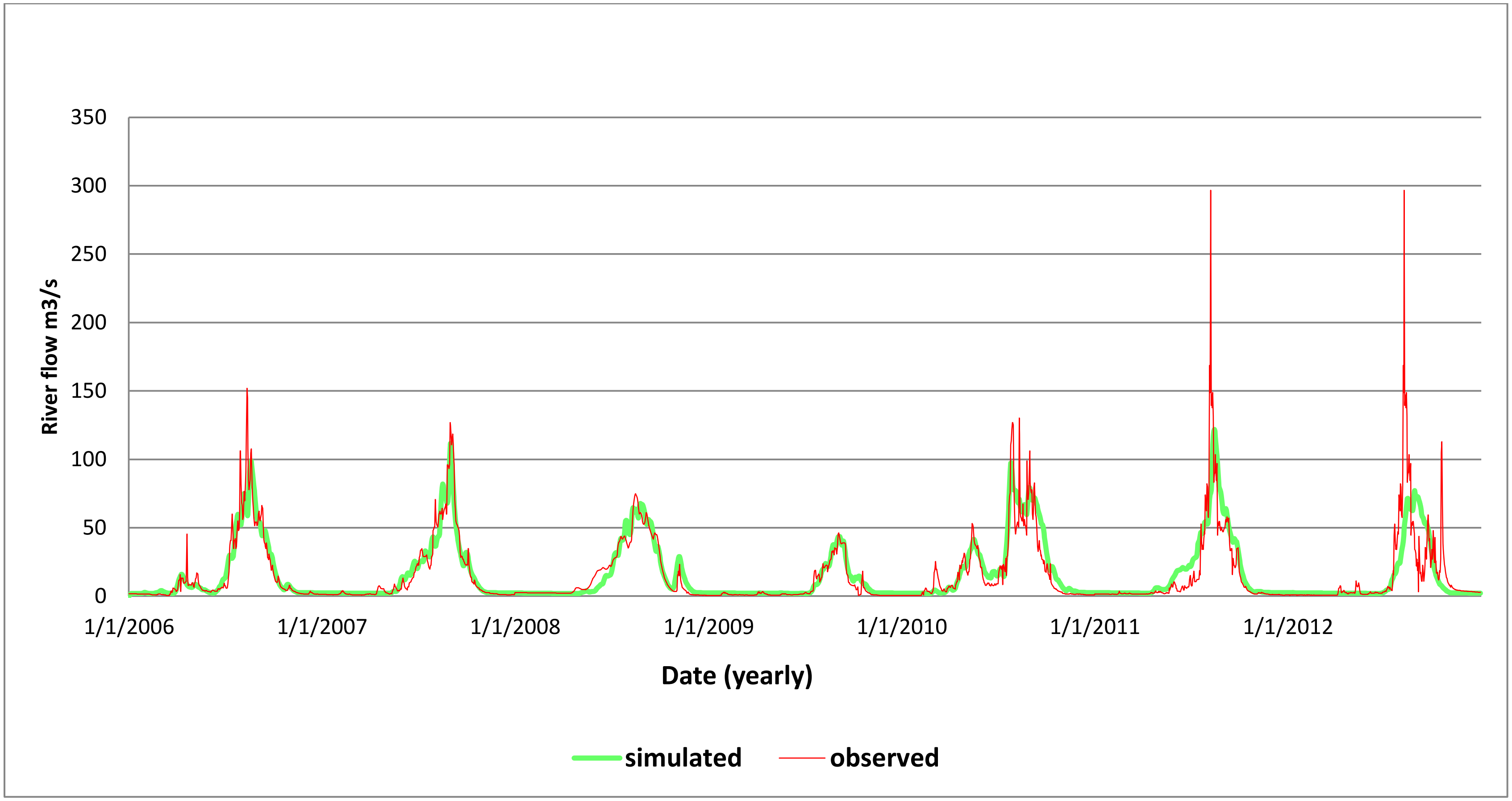
## Appendix 4. Hydrographs for simulated and observed runoff from Katar Sub-basins (1993-2012)



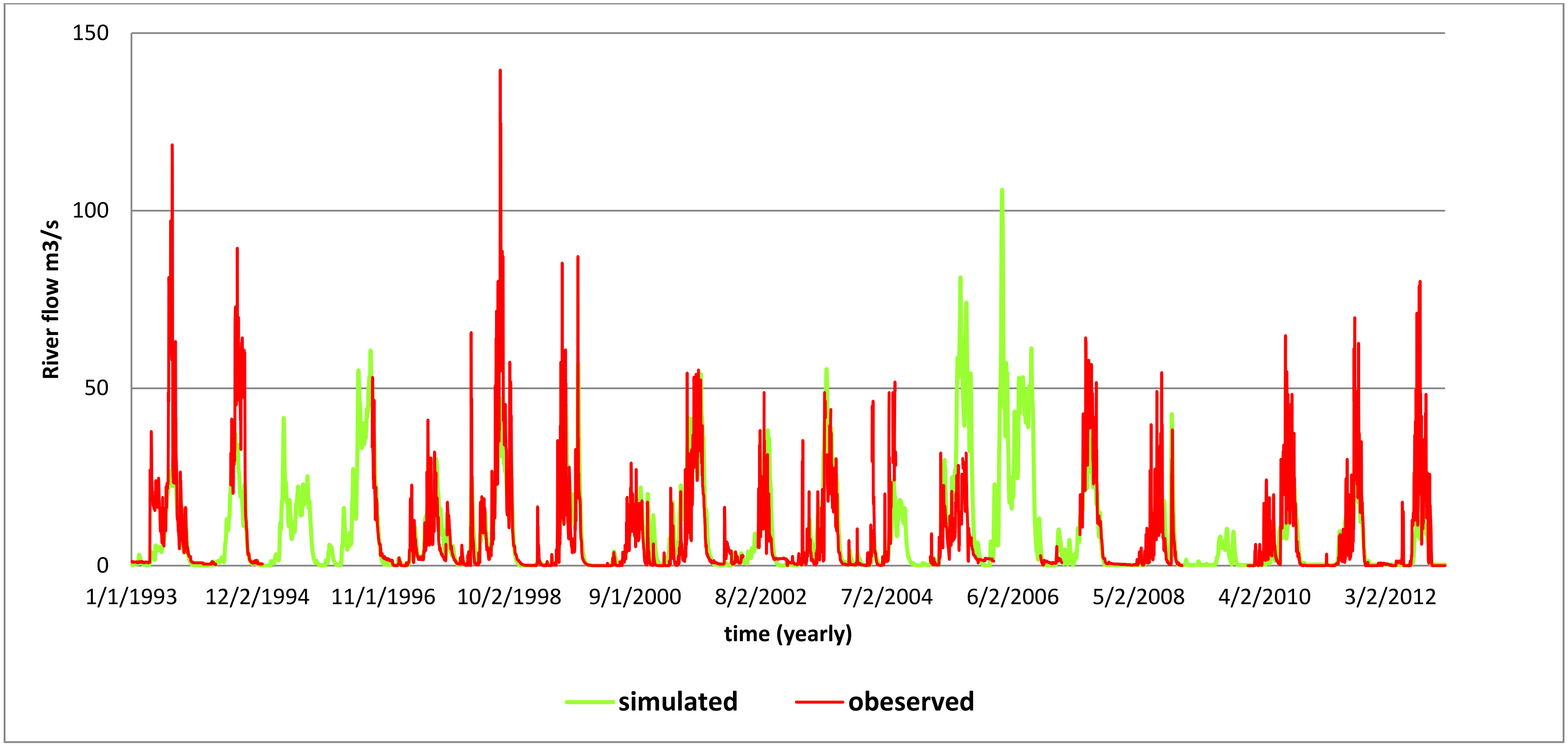
## Appendix 5. Simulated and observed runoff for Katar (1993-2005)



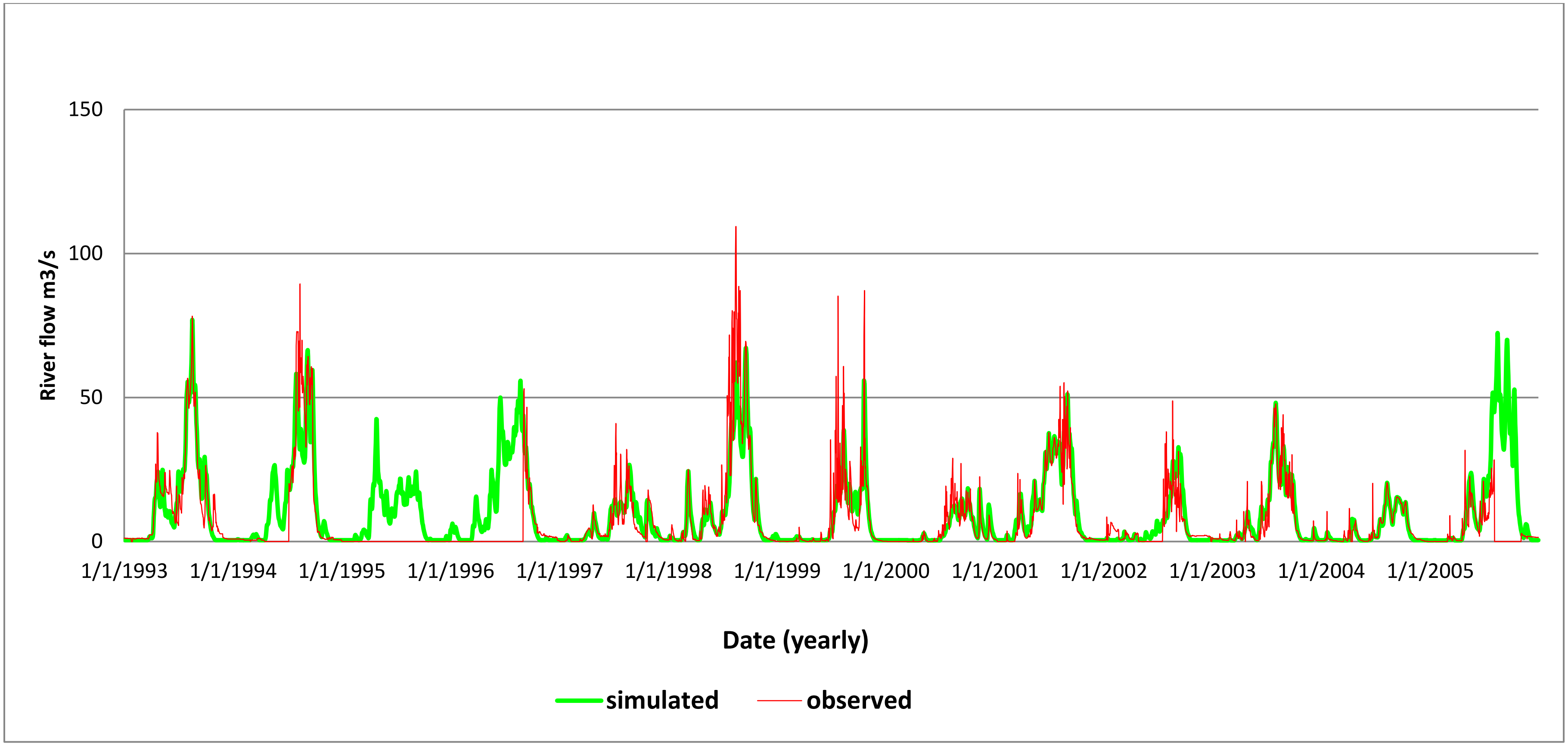
# Appendix 6. Simulated and observed runoff for Katar (2006-2012)



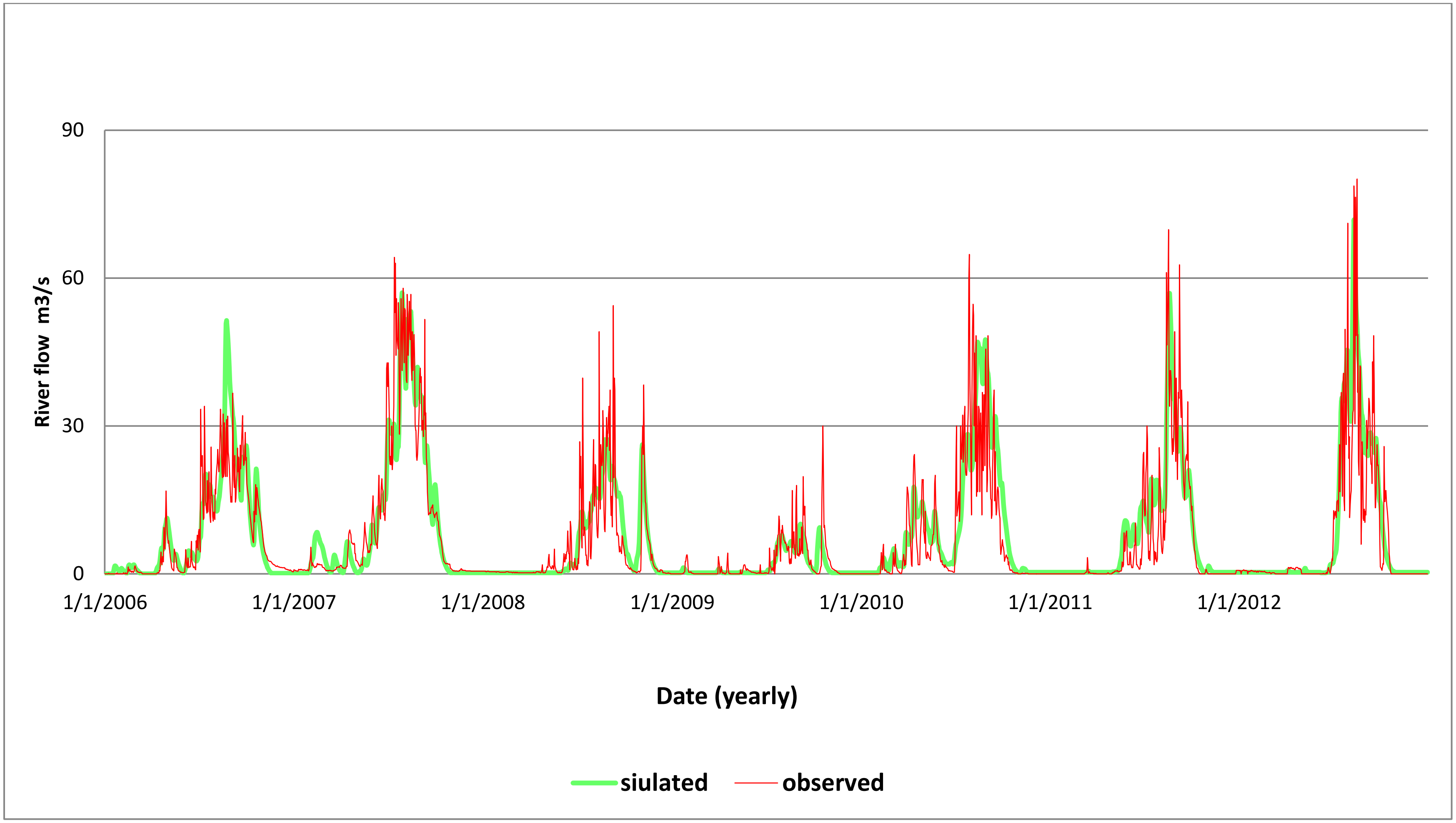
## Appendix 7. Hydrographs for simulated and observed runoff from Meki Sub-basins (1993-2012)



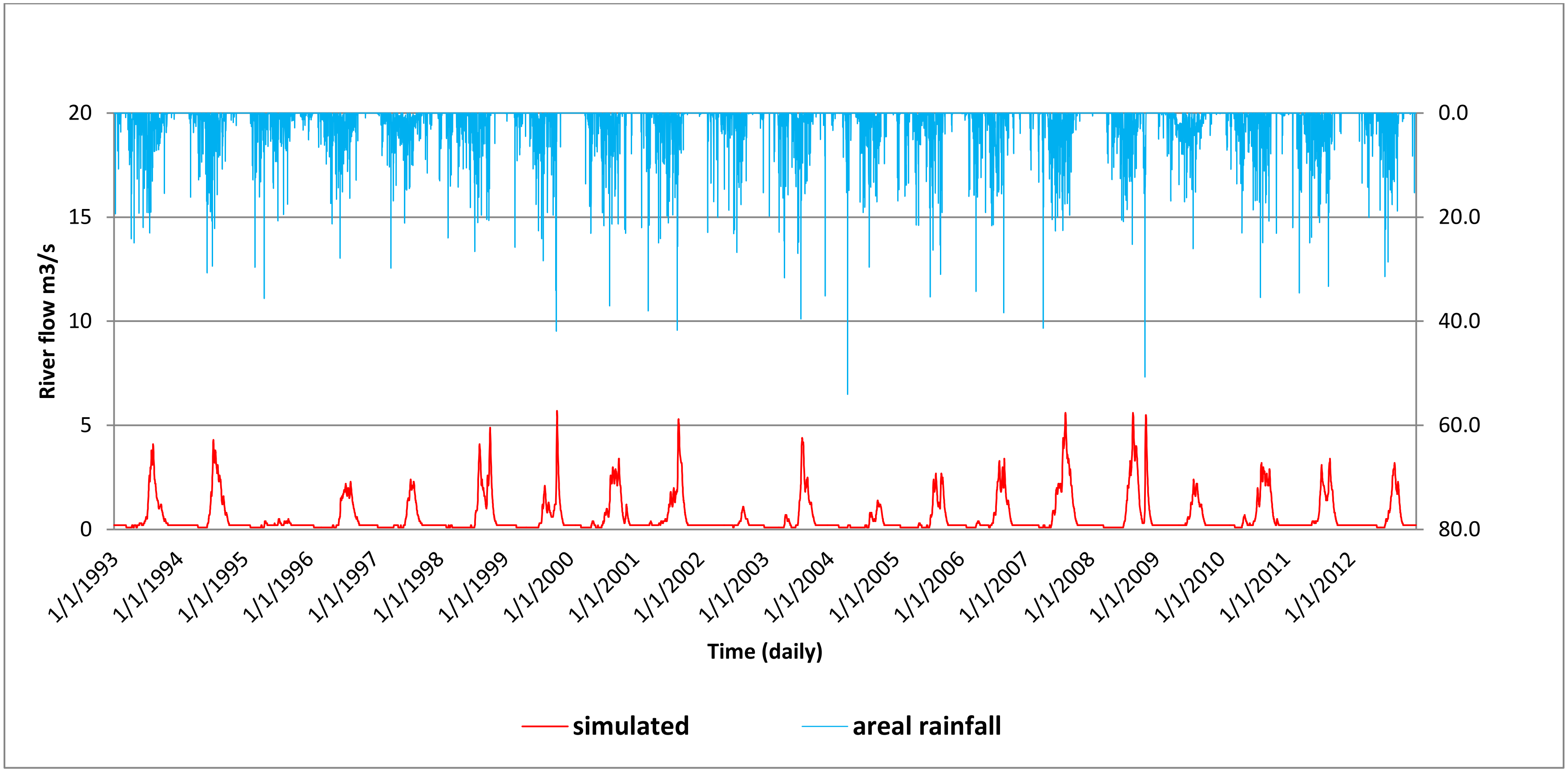
## Appendix 8. Simulated and observed runoff for Meki (1993-2005)



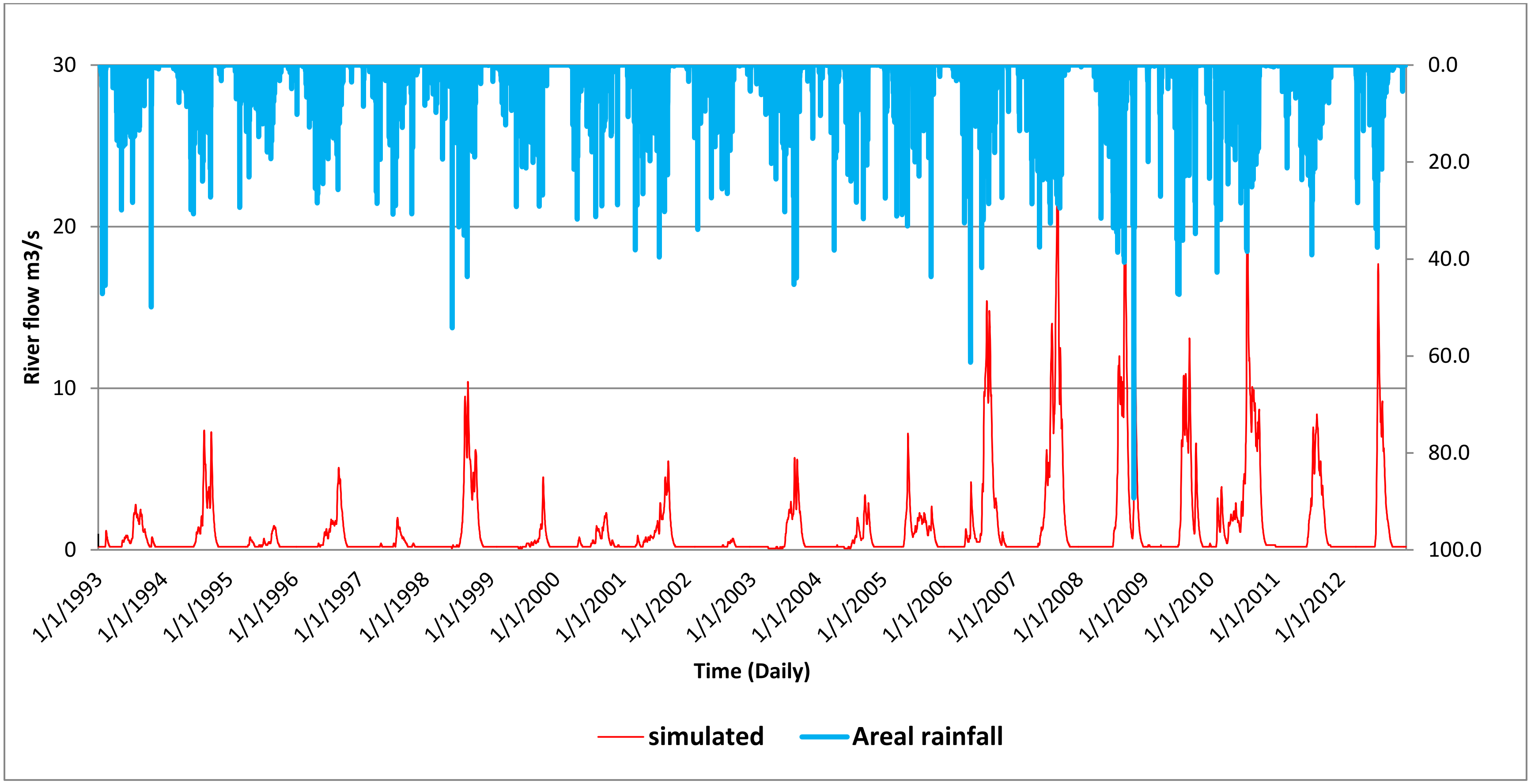
## Appendix 9. Simulated and observed runoff for Meki (2006-2012)



## Appendix 10. Hydrographs for simulated runoff from north un-gauged Sub-basins



## Appendix 11. Hydrographs for simulated runoff from south un-gauged Sub-basins



## Appendix 12. Hydrographs for simulated runoff from West un-gauged Sub-basins